

**PUBLIC NOTICE**  
**LOUISIANA DEPARTMENT OF ENVIRONMENTAL QUALITY (LDEQ)**

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**DRAFT BASIS OF DECISION DOCUMENT FOR THE FINAL REMEDY FOR  
CONTAMINATION OF THE PLAQUEMINE AQUIFER IN THE VICINITY OF THE  
CITY OF PLAQUEMINE**

**A. WILBERT AND SONS TRAILER PARK AI NUMBER 81438**

The LDEQ, Office of Environmental Assessment, will receive comments on the proposed Draft Decision Document for the Final Remedy for contamination of the Plaquemine Aquifer in the vicinity of the City of Plaquemine. **The area of contamination extends northward from north of LA Hwy 1148, southward to Haase Street, westward to the end of west Homestead Road and eastward to the Mississippi River levee.**

In 1997 and 1998, the Louisiana Department of Health and Hospitals (LDHH) sampled water wells at the Myrtle Grove Trailer Park in Plaquemine, Louisiana, and detected levels of vinyl chloride which exceeded Maximum Contaminant Levels (MCLs). Vinyl chloride was detected again during the March 2001 sampling event. LDHH notified the Louisiana Department of Environmental Quality (LDEQ) on March 29, 2001. The LDEQ immediately began a groundwater investigation to determine the source and extent of the contamination. The U.S. Environmental Protection Agency (EPA) joined the effort and provided expertise in modeling and an evaluation of the fate and transport of the contaminants in the aquifer.

**Written comments regarding this proposed decision may be submitted during the forty-five (45) day public comment period, to Ms. Soumaya Ghosn at LDEQ, Public Participation Group, P.O. Box 4313, Baton Rouge, LA 70821-4313. Written comments and/or written requests for notification must be received by 4:30 p.m., Monday, March 3, 2008. Written comments will be considered prior to a final decision.**

If LDEQ finds a significant degree of public interest, a public hearing may be held. LDEQ will send notification of the final decision to the applicant and to each person who has submitted written comments or a written request for notification of the final decision.

A copy of the draft basis of decision document and the Corrective Action Study are available for review at the LDEQ, Public Records Center, Room 127, 602 North 5<sup>th</sup> Street, Baton Rouge, LA. Viewing hours are from 8:00 a.m. to 4:30 p.m., Monday through Friday (except holidays). **The available information can also be accessed electronically on the Electronic Document Management System (EDMS) on the DEQ public website at [www.deq.louisiana.gov](http://www.deq.louisiana.gov).**

An additional copy may be viewed at the Iberville Parish Library, Headquarters, 24605 J. Gerald Berret Blvd., Plaquemine, Louisiana 70764.

Inquiries or requests for additional information regarding this action should be directed to Ms. Laurie Peacock, Environmental Technology Division, P.O. Box 4314, Baton Rouge, LA 70821-4314, (225)219-3393 or Fax (225) 219-3474.

**All correspondence should specify AI Number 81438.**

**Scheduled Publication Date: January 17, 2008**

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**The Louisiana Department of Environmental Quality's  
Basis of Decision Document  
For the  
Final Remedy for  
Contamination of the Plaquemine Aquifer in the  
Vicinity of the City of Plaquemine**

**A. Wilbert and Sons Trailer Park  
Agency Interest # 81438**

**Section 1 Introduction**

In 1997 and 1998, the Louisiana Department of Health and Hospitals (LDHH) sampled water wells at the Myrtle Grove Trailer Park in Plaquemine, Louisiana, and detected levels of vinyl chloride which exceeded Maximum Contaminant Levels (MCLs). Vinyl Chloride was detected again during the March 2001 sampling event. LDHH notified the Louisiana Department of Environmental Quality (LDEQ) on March 29, 2001. The LDEQ immediately began a groundwater investigation to determine the source and extent of the contamination. The U.S. Environmental Protection Agency (EPA) joined the effort and provided expertise in modeling and an evaluation of the fate and transport of the contaminants in the aquifer.

The purpose of the Basis of Decision is to identify the proposed remedy for addressing contamination at the site and explain the reasons for the preference. This document also describes the remedial options considered in the Remediation Study. With the issuance of the Basis of Decision, LDEQ would like to solicit public review and comment of the alternatives considered. Public input on all potential remedial alternatives, and on the information that supports the alternatives, is an important contribution to the remedy selection process. LDEQ may modify the proposed remedy or select another remedy based on new and/or substantive information presented through public comments. The public comment period for this Basis of Decision document begins \_\_\_\_ and ends on \_\_\_\_\_. During the public comment period, written comments must be postmarked or e-mailed by \_\_\_\_\_, submitted to [laurie.peacock@la.gov](mailto:laurie.peacock@la.gov) or mailed to:

Tom Harris, Administrator  
Environmental Technology Division  
P.O. Box 4314  
Baton Rouge, LA 70821-4314

LDEQ will address all comments received during the public comment period in the Response to Comments/Final Decision document (RTC). The RTC will explain LDEQ's rationale for the remedy selected to address contamination at the site. The preferred remedy in the Basis of Decision is a preliminary determination. The final remedy selected by LDEQ will be implemented through a Cooperative Agreement or Consent Order.

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## **Section 2 Risk Evaluation**

Since becoming aware of the vinyl chloride contamination, the LDEQ has taken actions to ensure that no private water wells within the area of the contamination are being used for drinking water or for watering vegetable gardens. This includes door-to-door surveys, public meetings, and capping of known wells.

The Plaquemine Aquifer is used as a secondary source of drinking water for the city of Plaquemine. Safe Drinking Water Act standards are used as acceptable limits for the two contaminants: cis-1,2-dichloroethylene has an MCL of 70 micrograms per liter (ug/L) and vinyl chloride has an MCL of 2 ug/L. Four sentinel wells have been installed near the City of Plaquemine's water supply wells to act as an advanced warning system for the movement of the plume toward the supply wells.

The *Study of Treatment Capability for the City of Plaquemine's Water Treatment* (December 2006) reported that the City of Plaquemine's water treatment facility is currently capable of removing vinyl chloride from influent water and that the aerator can reduce influent concentrations of 4 to 6 ppb to below the MCL of 2 ppb. The Study also revealed that any vinyl chloride in the influent would be subject to a two-step treatment process: aeration through a multi-cone aerator, which is estimated to remove 53 % to 67% of potential vinyl chloride, then subsequent filtering through the granular activated carbon filter system.

## **Section 3 Evaluation of Remedial Alternatives**

A Remediation Study was performed to evaluate the long-term need for remediation of the Plaquemine Aquifer and, if necessary, options for remediation. The Study was to include evaluation of, at a minimum, monitored natural attenuation, chemical injection, biostimulation, and no action at all. The plume's extent is approximately one mile by two miles by 180 feet below land surface; the highest concentration was 97 ppm (June 2001) and has been dropping over the six year monitoring period. The majority of the plume is below a heavily developed area; there is no known continuing source of contaminants.

The Remedial objectives are to permanently reduce vinyl chloride concentrations to at or below the federal drinking water MCL of 2 ug/L and to prevent vinyl chloride from impacting the quality of the City of Plaquemine's secondary drinking water source and throughout the aquifer. The following remedial alternatives were reviewed:

Monitored Natural Attenuation (MNA) – MNA is a potential option for reduction of the mass and concentration of contaminants in the environment. Remediation by natural attenuation depends upon natural processes such as dispersion, dilution, biodegradation, volatilization, hydrolysis, and sorption to attenuate contaminants. Choosing MNA as the means for remediation first requires groundwater modeling to predict when remediation objectives will be attained. A groundwater monitoring program must be in place as part of the *Performance Monitoring Plan*. The success of MNA alone would depend on the natural tendency for the Constituents of Concern (COC's) to degrade.

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Several mechanisms exist spatially within the Plaquemine Aquifer allowing for the natural breakdown of chlorinated compounds: direct aerobic metabolism, where oxygen is present; reductive dechlorination; iron reduction; and co-metabolic degradation where oxygen and methane are present. Monitoring wells currently exist in the Plaquemine area that may be used to monitor parameters indicative of the natural breakdown of chlorinated compounds existing in the aquifer. This alternative is minimally intrusive, with no extraction of large amounts of water for holding or processing, and supports the protection of human health and the environment.

The estimated cost for this option is \$2,122,690 over a timeframe of twenty years, with an installation of eleven additional wells in addition to the existing monitoring well network.

Pump and Treat – This remedy would include installation of extraction wells to remove contaminated groundwater until the remedial goal is met. An extraction flow rate of 2000 gallons per minute with a well spacing of approximately 2000 feet would be necessary for a period of approximately fifteen years. This method would allow the remedial goals to be met but would be prohibitive to implement due to the number of wells, location within a densely populated residential area and the scale of treatment. The areal extent of the contaminant plume is approximately one-mile by two-miles. Total groundwater anticipated to be extracted would be approximately 150 billion gallons over the timeframe of this alternative. Conveyance piping for the contaminated water from the extraction wells to a treatment plant would be significantly difficult to plan and install in residential areas. This remedy is not considered to be the best method due to the cost vs. benefit ratio, the widespread and heavily developed area of the plume, low concentrations of contaminants and that there is no known continuing source of contaminants to the plume.

The estimated cost for this option is \$123,669,486 over a timeframe of fifteen years. Included in this cost are: installation of ten 4-inch diameter monitoring wells to approximately 250 feet in depth, ten 12-inch extraction wells to approximately 250 feet in depth, plus associated pumps, treatment system, electrical lines and metering, and disposal costs.

In Situ Aerobic Bioremediation – This method uses the injection of hydrogen peroxide or pure oxygen to biostimulate direct microbial-catalyzed oxidation of vinyl chloride. Installation and scope of the system is prohibitive, as well as biofouling of the system over time. This remedy is not considered to be the best method due to the cost vs. benefit ratio, the widespread and heavily developed area of the plume, low concentrations of contaminants and that there is no known continuing source of contaminants to the plume.

The estimated cost for this option is \$63,751,377 over a timeframe of five years. Included in this cost is the installation of: ten 4-inch monitoring wells to a depth of 250 feet, 33 12-inch extraction wells to a depth of 250 feet, and 66 12-inch injection wells to a depth of 250 feet. Additionally, electrical lines and metering must be addressed, as well as piping to/from wells and installation of a treatment system.

In Situ Anaerobic Bioremediation – This remedial alternative would encompass the injection of a carbon-rich substrate, such as molasses to biostimulate reductive dechlorination of vinyl



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chloride. A groundwater recirculation system would be used to distribute the substrate in the aquifer. To apply this remedy over the entire area of the plume would involve a prohibitive number of injection wells and extraction lines. This remedy is not considered to be the best method due to the cost vs. benefit ratio, the widespread and heavily developed area of the plume, the depth to contaminants, low concentrations of contaminants and that currently, there is no known apparent continuing source of contaminants to the plume.

The estimated cost for this option is \$56,605,563 over a timeframe of five years. Similar to in situ aerobic bioremediation, it would require installation of: ten 4-inch monitoring wells to a depth of 250 feet, 33 12-inch extraction wells to a depth of 250 feet, and 66 12-inch injection wells to a depth of 250 feet. Additionally, electrical lines and metering must be addressed, as well as piping to/from wells and installation of a treatment system and tanks.

Chemical Oxidation – This remedy includes the injection of strong oxidants into the contaminated zone. Examples of these oxidants include: hydrogen peroxide, Fenton's Reagent, permanganate, persulfate, and ozone. The technical difficulties in establishing this remedy are similar to the pump and treat remedy in that many wells and associated piping would be required. This remedy is not considered to be the best method due to the cost vs. benefit ratio, the widespread and heavily developed area of the plume, low concentrations of contaminants and that there is no known continuing source of contaminants to the plume.

Zero-Valent Iron - Zero-valent iron is generally applied as a permeable reactive barrier. Iron particles can be injected into the aquifer through a line of wells to form this barrier. The zero-valent iron provides an electron source for dechlorination of vinyl chloride. This technology is proven in small scale conditions. Wells would need to be placed at intervals throughout the treatment zone on the order tens of feet; the amount of iron required for the many wells would also be prohibitive. This remedy is not considered to be the best method due to the cost vs. benefit ratio, the widespread and heavily developed area of the plume, low concentrations of contaminants and that there is no known continuing source of contaminants to the plume.

## **Section 4 Selection of the Preferred Alternative**

For the Basis of Decision, individual corrective measure alternatives are described and evaluated against criteria outlined in the Guidance on RCRA Corrective Action Decision Documents, Office of Solid Waste and Emergency Response (OSWER) Directive 9902.6. This guidance document outlines the four general standards for remedy selection of 1) overall protection of human health and the environment, 2) attainment of cleanup standards, 3) control of the sources of releases, and 4) compliance with regulatory standards for hazardous waste management. There are five criteria used for remedy selection and they are: 1) long-term reliability and effectiveness, 2) reduction of toxicity, mobility and volume of wastes, 3) short-term effectiveness, 4) implementability, and 5) cost.

Based on a review of these standards, LDEQ and EPA are proposing Monitored Natural Attenuation (MNA) as the preferred remedy. MNA is a widely accepted remedial approach where sources have been addressed and the environment is conducive to natural chemical breakdown of contaminants. MNA is not a "no action" approach, because it requires long-term

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monitoring to assure that the remedial objectives are met within time frames as predicted by modeling results.

Following the criteria in Chapter 5 of the Louisiana Revised Statutes, Part VI., Monitored Natural Attenuation (MNA) is the preferred alternative for the overall protection of human health and the environment as demonstrated by:

- Use of pre-existing monitoring well network;
- Additional wells unobtrusively installed;
- Both technically and administratively straightforward;
- Relatively low cost for additional well installations and sampling over the projected timeframe of the project.

With the implementation of MNA, LDEQ and EPA will require a Contingency Plan to address performance of the remedy if results are unacceptable. If the plume reaches the City of Plaquemine sentinel wells at levels above the MCLs for the constituents of concern, a response action will take place which will involve the implementation of a more aggressive remedy. The Contingency Plan will provide options for correcting the course of the remedy, which may include a treatment or containment measure.

## **Section 5 Summary of Review Criteria**

The following discussion profiles the performance of the proposed remedy against the four general standards for corrective measures and the five remedy decision factors. For a review of the other alternatives, see the Attachment.

The LDEQ and EPA have agreed that MNA will meet the overall criteria of protection of human health and the environment for the following reasons. If concentrations of vinyl chloride continue to be below the MCL at the sentinel wells, then the attainment of cleanup standards will be maintained. Continued sampling and collection of groundwater data will ensure that predicted attenuation rates are correct, or may serve to show if there are source areas that need to be addressed. The monitoring program will continue according to regulatory requirements. The proposed remedy of MNA will have long-term effectiveness as long as degradation is occurring. Data collected to date reliably show that natural attenuation is occurring, and this process will continue to occur. The natural breakdown process will result in the reduction of toxicity and volume of contaminants. MNA does not however, affect the mobility of vinyl chloride in the aquifer. EPA and LDEQ will rely on the collection of data from the City sentinel wells as an early warning system to determine the concentration of vinyl chloride near the City public supply wells. MNA does not prove to have short term effectiveness because it relies on the natural breakdown processes to occur. Since the public water supply has not been affected, there is not an urgent need for short term effectiveness. MNA meets the remediation standard of being protective of human health and the environment, has a reasonable cost vs. benefit ratio, and is minimally intrusive, with no extraction of large amounts of water for holding or processing. This level of remediation is appropriate for the large size and low concentration of the plume and that there is no known continuing source of contamination.

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## Section 6 Performance Monitoring and Review

If the remedy is not effective, a *Contingency Plan* will be implemented, which may involve a treatment or containment corrective measure. The *Contingency Plan* will include corrected timeframes for achieving the remedial objective.

A requirement of the implementation of the preferred remedial alternative is a *Performance Monitoring Plan* to determine the effectiveness of the remedy and to optimize the groundwater monitoring system for compliance monitoring. The *Performance Monitoring Plan* will outline a clear definition of the monitoring frequency, sampling locations and data interpretation.

A *Performance Review Plan* will outline 5-year review of sampling data and comparison to modeling results to determine if the MNA is moving toward the remedial goal, in the appropriate timeframes, as suggested in the Remediation Study. It will also include recommendations for any needed changes in performance monitoring. The *Performance Review Plan* will have a clear decision logic that defines the appropriate response action in the Contingency Plan to implement when remedial objectives are not being met, such as detection of vinyl chloride above MCLs in the sentinel wells and/or a lack of degradation of the plume or plume mass. As risk and the plume are reduced, a plan for phase-out of performance monitoring will be included.

## Section 7 Path Forward

The issuance of this Draft Basis of Decision Document begins a thirty (30) day comment period that commences on the day of publishing a public notice of the public comment period in the newspaper of general circulation in Iberville Parish. Comments should be addressed to:

P.O. Box 4314  
Baton Rouge, LA 70821-4314

The letter should contain the site name, **A. Wilbert and Sons Trailer Park**, and the **Agency Interest Number (AI) 81438**. LDEQ and the EPA will consider the comments and information submitted during the public comment period and will write a Response to Comments/Final Decision Document.

Signed this \_\_\_\_\_ day of \_\_\_\_\_ 2007

By:

\_\_\_\_\_  
Thomas F. Harris, Administrator  
Environmental Technology Division  
Louisiana Department of Environmental Quality

\_\_\_\_\_  
Mark Hansen, Chief  
Hazardous Waste Enforcement Branch  
U.S. Environmental Protection Agency

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# **ATTACHMENT**

**Remediation Study  
April 2007**

# TAYLOR PORTER

ATTORNEYS AT LAW

Founded 1912

# RECEIVED

APR 30 2007

Underground Storage  
Tanks Division

April 27, 2007

via Certified U.S. Mail

Return Receipt Requested

Receipt No. 7004 1160 0003 2570 9193

Wilbert F. Jordan, Jr., Assistant Secretary  
Louisiana Department of Environmental Quality  
Office of Environmental Assessment  
P.O. Box 4314  
Baton Rouge, LA 70821-4314

Return Receipt Requested

Receipt No. 7004 1160 0003 2606 8756

Mark Hansen  
U. S. Environmental Protection Agency  
Hazardous Waste Enforcement Branch, Chief  
Compliance Assurance & Enforcement Division  
Region 6 - Mail Code: 6EN-H  
1445 Ross Avenue, Suite 1200  
Dallas, TX 75202-2733

RE: Cooperative Agreement between the State of Louisiana, Department of  
Environmental Quality, and United States Environmental Protection Agency and  
The Dow Chemical Company in the Matter of the Plaquemine Aquifer -  
RCRA-06-2005-0906

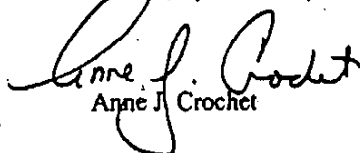
Dear Mr. Jordan and Mr. Hansen:

Pursuant to our discussions with the Department, enclosed please find Remediation Study  
(April 2007) that is being submitted pursuant to Section III. of the Cooperative Agreement.

Thank you for your attention to this matter.

Very truly yours,

TAYLOR, PORTER, BROOKS & PHILLIPS L.L.P.



Anne J. Crochet

AJC:dlm

Enclosure

cc: Louis Buatt, LDEQ, via U.S. Mail  
Nancy Fagan, USEPA, via U.S. Mail

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## Remediation Study

pursuant to

Cooperative Agreement Between the State of  
Louisiana Department of Environmental Quality  
and the United States Environmental Protection  
Agency and The Dow Chemical Company in the  
Matter of the Plaquemine Aquifer

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April 2007

# Battelle

*The Business of Innovation*

Battelle—Pacific Northwest Division  
Richland, Washington 99352

## **Remediation Study**

pursuant to

**Cooperative Agreement Between the State of Louisiana Department of  
Environmental Quality and the United States Environmental Protection  
Agency and The Dow Chemical Company in the Matter of the  
Plaquemine Aquifer**

**April 2007**

**Bartelle—Pacific Northwest Division  
Richland, Washington**

## Executive Summary

Pursuant to the Cooperative Agreement and in accordance with Battelle's work plan, Battelle has performed a remediation study. This study evaluates the long-term need for remediation of the Plaquemine Aquifer and, as necessary, evaluates options for remediation by identifying currently available remediation options and then evaluating appropriate remediation options including the four (4) remediation options enumerated in the Cooperative Agreement: monitoring and natural attenuation, chemical injection, biostimulation, and no further action.

Specifically, the study finds that vinyl chloride contamination exists in portions of the remediation study area (in the vicinity of Plaquemine, LA) at levels above the Maximum Contaminant Level (MCL), identifies options to decrease vinyl chloride concentrations within the remediation study area to levels at or below the MCL, and evaluates potential remedial options identified for the remediation study area including the four (4) remediation options specified in the Cooperative Agreement. The study concludes that there are no active remedial options that are appropriate for the remediation of vinyl chloride contamination to levels at or below the MCL in the contaminated portions of the remediation study area. Instead, the study concludes that the preferred option is a Monitored Natural Attenuation remedy.

In reaching the conclusions stated above, the following factors are pertinent:

1. The conventional water quality and aesthetics of water from the Plaquemine Aquifer are generally poor due to hardness and concentrations of iron. From 1967 until May 16, 2004, the primary source of water for the City of Plaquemine had been from deep wells owned by the City of Plaquemine and located near the Port Allen (Louisiana) Lock at the Intracoastal Waterway. An exception was the Myrtle Grove Trailer Park, which was not connected to the City of Plaquemine's water supply until March 2001. After May 16, 2004, until present, the City of Plaquemine has continued to use the Port Allen wells as a primary water source, but also uses water from portions of the Plaquemine Aquifer not contaminated with vinyl chloride as a supplemental water source. Active remediation of the vinyl chloride contamination in the study area does nothing to improve the conventional water quality and aesthetics of the aquifer.
2. More significantly, the Plaquemine Aquifer in most of the remediation study area is not usable for drinking water without treatment because of the presence of arsenic in excess of the drinking water standard. The U. S. Environmental Protection Agency (EPA) identifies arsenic as a significant groundwater contaminant and has recently lowered the drinking water standard from 50 ppb to 10 ppb. Additionally, the U.S. Department of Health and Human Services lists arsenic as number one in the Priority List of Hazardous Substances. Further, natural arsenic-containing minerals can serve as a continuing source for arsenic in the groundwater. Applying active remediation for vinyl chloride would have minimal benefit because this groundwater must be treated to remove arsenic in order to meet drinking water standards. Active remediation of vinyl chloride in the



remediation study area does nothing to reduce the excessive levels of arsenic to at or below the MCL. In fact, some potential remedies for vinyl chloride may increase the arsenic concentrations.

3. Additionally, active remedies are not feasible to apply. The scale of remediation for the portions of the Plaquemine Aquifer potentially contaminated with vinyl chloride above the drinking water standard results in technical and administrative issues that render active remediation technologies unsuitable. An active remediation operation at such a scale would require significant industrial-type activities in residential areas.
4. Evaluation of vinyl chloride and groundwater geochemical data available in the remediation study portion of the Plaquemine Aquifer using published EPA protocols for assessing natural attenuation of groundwater contamination indicates that 1) conditions are favorable for vinyl chloride degradation, and 2) the estimated rate of degradation is suitable for a Monitored Natural Attenuation (MNA) remedy. The study indicates that it is reasonable to expect natural attenuation processes to reduce the vinyl chloride contamination to levels at or below the MCL in the Plaquemine Aquifer. A site-specific approach for MNA could be applied, and periodic monitoring would be an effective mechanism to ensure that the vinyl chloride contamination does not expand and does not impact the City of Plaquemine water supply wells. Thus, MNA is the recommended approach to the vinyl chloride contamination.

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## 1.0 Introduction

The remediation study was prepared pursuant to the *Cooperative Agreement between the State of Louisiana Department of Environmental Quality and The United States Environmental Protection Agency and The Dow Chemical Company in the Matter of the Plaquemine Aquifer* effective October 6, 2004 (Cooperative Agreement). The remediation study area is near Plaquemine, Louisiana, as shown in Figure 1. Diffuse vinyl chloride at low concentrations has been detected in the groundwater of the Plaquemine Aquifer in portions of the remediation study area. For example, vinyl chloride was detected at low levels in the Myrtle Grove Trailer Park well system where the aquifer had been used as a drinking water source, and this situation was investigated by the Agency for Toxic Substances and Disease Registry (ATSDR). In its May 17, 2004 Health Consultation, the ATSDR concluded: "Although exposure occurred, the levels of the chemicals detected were below levels likely to result in adverse health effects. ATSDR has, therefore, categorized the Myrtle Grove Trailer Park site as presenting No Apparent Public Health Hazard" (U.S. Department of Health and Human Services 2004). In a December 11, 2006 Health Consultation, the ATSDR evaluated wells with detectable levels of vinyl chloride in the remediation study area and concluded that exposure to water from these wells is unlikely to result in harmful health effects (U.S. Department of Health and Human Services 2006). Sampling and analysis of the Plaquemine Aquifer within the remediation study area has also been conducted by the State of Louisiana Department of Environmental Quality (LDEQ), the United States Environmental Protection Agency (EPA) and The Dow Chemical Company.

The scope of the remediation study was to evaluate both the long-term need for any remediation of the Plaquemine Aquifer and feasible remediation options. The evaluation was based on the study site-specific data. A conceptual model was developed using the site-specific data to provide a framework for the remediation study. The study identified potential remediation methods and evaluated remedial alternatives against applicable criteria. The report concludes with a recommendation for remediation of the Plaquemine Aquifer.

The report is organized in five sections: Section 1 is the introduction; Section 2 describes the conceptual model framework and remediation objectives for the remediation study; Section 3 identifies potential remediation methods; Section 4 evaluates the remedial alternatives; and Section 5 presents the conclusions.

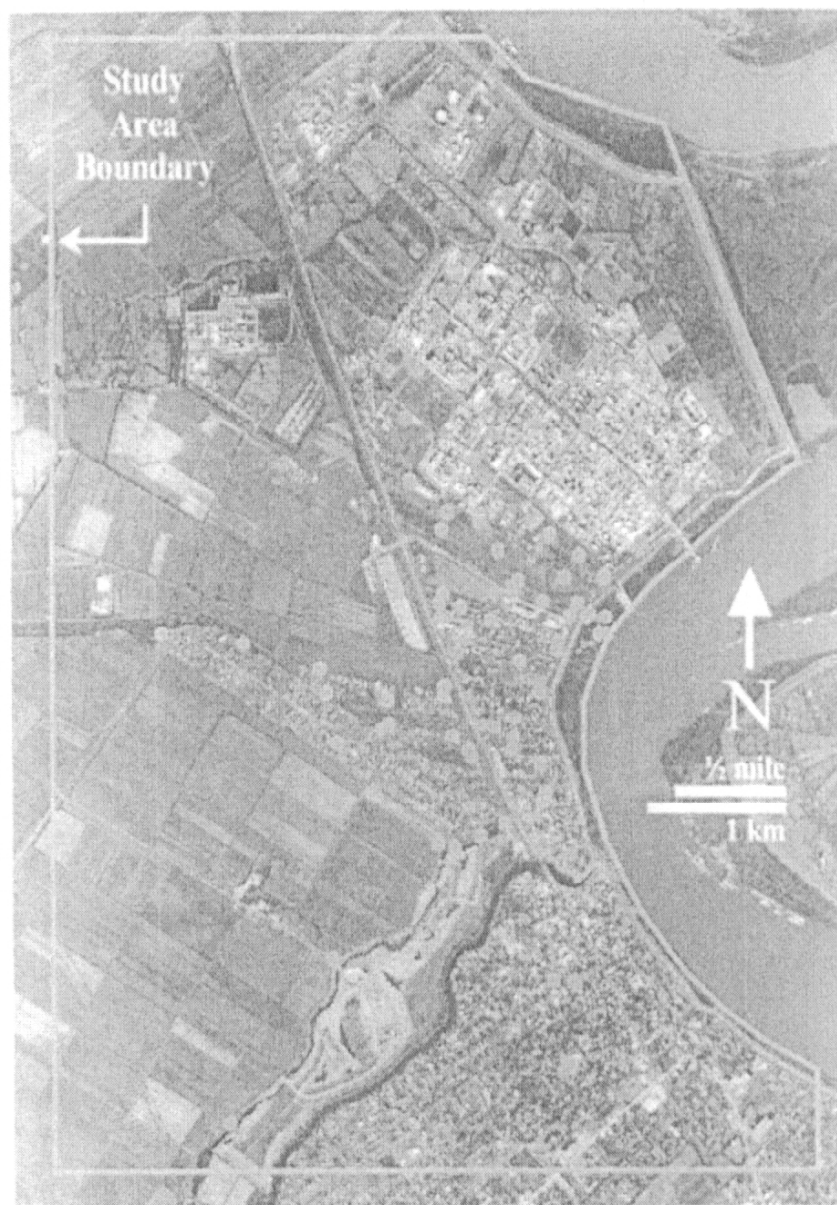


Figure 1 Remediation study area boundary. The blue dots indicate locations that have been sampled for vinyl chloride within the Plaquemine Aquifer

## 2.0 Conceptual Model and Remediation Objectives

Section 2.1 identifies the conceptual model of the remediation study area and provides a framework for evaluation of remediation alternatives. Remediation objectives are defined in Section 2.2.

### 2.1 Conceptual Model

The following sections describe the conceptual model of the remediation study area for the purposes of the remediation study. The conceptual model identifies the attributes of the remediation study area with respect to hydrogeology, geochemistry, and contaminant distribution using site-specific data of appropriate quality. The hydrogeology is generalized to enable comparative analysis of remediation options, yet honors the site-specific data in establishing the hydrogeologic setting.

#### 2.1.1 Regional Context

The Plaquemine Aquifer is a regional aquifer of deltaic and alluvial deposits of sand and gravel underlain by clay/silt layers of variable thicknesses and spatial extent. Within the remediation study area, the Mississippi River channel cuts into the aquifer at the outside of a river bend, and the river is in hydraulic connection with the aquifer. Salt-water encroachment is not currently an issue within the remediation study area. The aquifer is highly transmissive, with specific capacities of water wells ranging from 6 to 150 gpm per foot of drawdown (Whiteman 1972). Water quality from the aquifer is poor with the groundwater being hard and containing troublesome amounts of iron (Whiteman 1972). Water in many areas of the Plaquemine Aquifer must be treated prior to use as drinking water due to the presence of arsenic above the MCL (LDEQ 2002).

The near surface soils of the remediation study area consist of a thin veneer of natural levee deposits, underneath which exist backswamp and then lacustrine deposits of the Mississippi River from the Holocene era. These backswamp and lacustrine deposits occur from land surface to approximately -80 ft mean sea level (MSL – used as equivalent to the North American Vertical Datum of 1988 [ACSM, 1992] in this report) and are composed of horizontal lenses and seams, and layers of soft- to medium-gray clays, silty clays, and clayey silt and silty sand. Decayed organic material is present in some of these layers. Below these Holocene deposits is the Plaquemine Aquifer (the local name for the Mississippi River Alluvial Aquifer), which is encountered at approximately -80 ft MSL in the remediation study area. The Plaquemine Aquifer consists of alternating coarse- and fine-grained materials including deposits of silty sand, medium-to-coarse sand and gravel, and several laterally large clay layers. The remediation study is focused on the upper 150-ft-thick portion of the Plaquemine Aquifer (from -80 to -230 ft MSL) consisting of sandy material and underlain by a clay layer. For the purposes of the study, this 150-ft portion of the aquifer is simply referred to as the “Plaquemine Aquifer” in this report.

The City of Plaquemine uses about 1.3 million gallons per day (MGD) of water. The primary source of water for the City of Plaquemine is from deep wells owned by the City of Plaquemine and located near the Port Allen (Louisiana) Lock, approximately 10 miles north of the remediation study area. This water source is supplemented as needed by water supply wells outside the area of vinyl chloride contamination and located in the City of Plaquemine. Water from the City of Plaquemine wells is treated by aeration, clarification, filtration, and chlorination prior to use as a drinking water supply by the city. Although there are three water supply wells located in the City of Plaquemine, these wells are only operated one at a time when needed to supply water to the water treatment facility.

### **2.1.2 Physical Configuration of Aquifer**

For the remediation study, the Plaquemine Aquifer was conceptualized as a uniform sandy aquifer at a depth interval of -80 to -230 ft MSL with 100 ft of clay/silt top stratum between the aquifer and the ground surface and underlain by a clay aquitard. There are borehole data that indicate aquifer materials ranging from silty sand to coarse sand with some gravel. This type of variation in aquifer properties was assumed not to impact the evaluation of remedies considered in this study because all of these aquifer materials have relatively high hydraulic conductivity, and a single hydraulic design across these materials would be suitable to distribute additives or extract groundwater. Figures 2 and 3 show the conceptual model plan and cross-section view of the aquifer in the remediation study area, respectively.

### **2.1.3 Hydraulic Conceptual Model**

The Plaquemine Aquifer is a confined aquifer. Data obtained from wells located within the remediation study area indicate that water elevations at monitoring locations in the Plaquemine Aquifer range from approximately 2 to 28 ft above MSL. Frequent measurements of water levels in a dense network of piezometers and wells within the remediation study area show that flow in the Plaquemine Aquifer is away from the river at high river stages. During periods of rapidly declining river stage, flow in the Plaquemine Aquifer is either static or very slightly toward the river. At low river stages, flow is again generally away from the river. The net groundwater flow direction in the remediation study area is to the west. Pumping at the City of Plaquemine water supply wells does not significantly change the net direction of groundwater flow in the portions of the remediation study area where vinyl chloride has been measured at concentrations greater than the MCL.

Appendix A contains details of the hydraulic conceptual model.

### **2.1.4 Contaminant Distribution**

The groundwater constituent concentration data considered in the study were compiled from data in Naymik (2004) and subsequent sampling events. Data from the following sampling events were utilized:

- U.S. Department of Health and Human Services sampling events at Myrtle Grove wells conducted 1994, 1997, 1998, 2001;
- LDEQ semi-annual sampling events of wells conducted June 2001 through August 2004;

- Dow sampling events of wells conducted 2001, 2005, 2006;
- Dow (South Perimeter Groundwater Study) sampling events of borings conducted 2001;
- LDEQ sampling event at Myrtle Grove wells conducted 2002; and
- Cooperative Agreement sampling events of wells conducted 2005 to the first quarter of 2007.

Contamination within the remediation study area is currently being monitored at nineteen (19) locations as part of the Cooperative Agreement. Additionally, groundwater samples were collected and analyzed at six (6) other locations (DEQ FF, DEQ HH, DEQ L, DEQ R, Myrtle Grove 1, Myrtle Grove 2) in the second quarter of 2006. Figure 4 shows the locations in which the maximum vinyl chloride concentrations exceeded the MCL based on 2006 and first quarter 2007 data, representing the most recent analytical data available at the time of this report.

**Chlorinated Contaminants.** Naymik (2004) presented historical groundwater constituent data for the remediation study area available at the time of that report. These data show some concentrations of vinyl chloride above the drinking water standard MCL of 2 ppb that are found sporadically distributed over the remediation study area without a distinct or typical single plume shape (i.e., there is no single distinct progression of contaminant concentrations along the direction of groundwater flow). Data in Naymik (2004), as well as recent data, indicate a significant spatial variation in the concentration of vinyl chloride laterally and vertically in the remediation study area. Because of the diffuse and non-continuous nature of the contamination across the remediation study area, the volume and extent of contamination was estimated for purposes of evaluating remedial options. Estimation of the treatment volume was conducted in a conservative manner using the maximum vinyl chloride concentration data from current and historical data and a standard data interpolation technique. The data interpolation technique uses linear interpolation based on the concentrations and relative location of each data point in the aquifer to calculate the area where the vinyl chloride concentration is estimated to be 2 ppb or greater. For the purpose of evaluating remediation technologies in the remediation study, the thickness of the treatment volume extends from -80 to -230 ft MSL in the Plaquemine Aquifer (150-ft thick). The treatment volume for the study was calculated as the area estimated by interpolation,  $4.7\text{E}7 \text{ ft}^2$  (e.g., an area ~6000 ft by 8000 ft), multiplied by the 150-ft thickness, resulting in an estimated treatment volume of  $7.0\text{E}9 \text{ ft}^3$  (261 million cubic yards). The amount of groundwater in this treatment volume is  $2.1\text{E}9 \text{ ft}^3$  (77 million cubic yards; 15.8 billion gallons), calculated using a porosity value of 0.3. The method for estimating the treatment volume of the contaminated area is considered conservatively high in terms of meeting the remediation goals identified for the study.

Within the treatment volume of the aquifer, data indicate only low concentrations of vinyl chloride with no distinct progression of concentrations such as contaminant plume development that would be expected to follow the groundwater flow pattern. Vinyl chloride data exhibit a distribution with isolated pockets of concentration above 10 ppb and with no correlation to the large-scale (>1,500 ft) groundwater flow trends. The presence of cis-1,2-dichloroethene (DCE)



in the aquifer may be a potential precursor to vinyl chloride in reductive biological transformation of chlorinated ethene compounds and may influence the concentration of vinyl chloride over time. However, the DCE is at low concentration (4.5 ppb or less for 2006/2007 data) and would produce only very low concentrations of vinyl chloride. For instance, using the maximum DCE concentration data in 2006/2007 (up through January 22, 2007, the most recent data available at the time of this report), if all of the DCE at a monitoring location were immediately converted to vinyl chloride, the resulting vinyl chloride concentration from DCE would be above the MCL at only 3 of the 25 monitoring locations. At these locations, the vinyl chloride concentrations from DCE conversion would range from 2.4 to 2.9 ppb. This estimate is conservative because (1) all of the DCE may not degrade to vinyl chloride – DCE can be degraded to other non-hazardous compounds under the conditions found in the Plaquemine Aquifer (Bradley and Chapelle 1997, 2000; Chang and Alvarez-Cohen 1996); (2) degradation of DCE occurs over time, not immediately; and (3) this estimate does not consider concurrent attenuation of vinyl chloride. Therefore, it is unlikely that DCE would make any significant contribution to vinyl chloride contamination in the remediation study area.

As shown in Naymik (2004) and in more recent data, DCE concentration data are all below the MCL of 70 ppb and exhibit a spotty distribution, as do the vinyl chloride data. As such, the data do not suggest a single source of vinyl chloride or DCE contamination or that there is a significant continuing source of vinyl chloride or DCE contamination. There are no data (Naymik 2004 and more recent data) indicating the presence of higher chlorinated ethene compounds at concentrations above the quantitation limit that may serve as "parent" compounds for in situ production of vinyl chloride and DCE by biological transformation processes. The study evaluated remediation alternatives only with respect to remediation of dissolved phase and associated sorbed phase vinyl chloride (using an equilibrium partitioning relation) and assumed no new or significant continuing sources of vinyl chloride to the remediation study area.

**Arsenic.** Arsenic concentrations based on filtered groundwater samples throughout most of the defined remediation volume exceed the 10 ppb MCL for arsenic (Figure 5). Figure 5 also shows the small number of locations where arsenic concentration is below the MCL based on available data. Arsenic is a constituent in many mineral forms, most abundantly in sulfide minerals (e.g., pyrite), but also associated with oxide and hydrous metal oxides where the arsenic may be part of the mineral structure or a sorbed species (Smedley and Kinniburgh 2002). Data compiled by the LDEQ (LDEQ 2005) at three sampling locations for the Mississippi River near Plaquemine, Louisiana, indicate that the average arsenic concentrations in the river were about 6 ppb between 1978 and 1992 and about 1.8 ppb between 1992 and 2004. Arsenic has also entered the environment at the ground surface through human activities such as sugar cane farming, cattle dipping, application as a pesticide (e.g., insects, weeds, fungi), and use as a wood preservative (Naymik 2004).

Nationally, there are a number of aquifers containing arsenic at concentrations above the MCL of 10 ppb (USGS 2000). EPA identifies arsenic as a significant groundwater contaminant and has recently lowered the drinking water standard from 50 ppb to 10 ppb. Additionally, the

U.S. Department of Health and Human Services recognizes arsenic as a health hazard and lists arsenic as number one in the Priority List of Hazardous Substances (U.S. Department of Health and Human Services 2006; ATSDR 2005). Because EPA recognized the increased need for arsenic treatment due to the lowered MCL for arsenic, a description of treatment processes for arsenic was recently developed by the EPA in 2002 (EPA 2002a). Groundwater quality reports have been compiled by the LDEQ for the Mississippi River Alluvial Aquifer System. The most recent groundwater quality report for the Mississippi River Alluvial Aquifer System (LDEQ 2002) identified wells with arsenic concentrations above the 10 ppb MCL in the aquifer, including wells in Iberville Parish. In the remediation study area, about 90% of the wells with arsenic data (filtered groundwater samples) have concentrations above the MCL. Based on the prevalence of arsenic contamination above the MCL, groundwater in many portions of the remediation study area would require treatment prior to use as drinking water.

#### **2.1.5 Geochemical Conceptual Model**

Geochemical data were compiled and evaluated to determine the prevailing geochemical conditions in the remediation study area. Detailed analysis of these data is presented in Appendix B. The analysis supports the conclusion that while there are individual wells within the aquifer that have conditions differing from the average geochemical conditions, there are not large groups of contiguous wells that have conditions different from the average. Therefore, it is reasonable to base the remediation study on the average geochemical conditions.

### **2.2 Remediation Objectives**

For the purpose of the remediation study, the remedial action objective will be to permanently decrease vinyl chloride concentrations to at or below the MCL defined in the federal drinking water standards within the remediation study area of the Plaquemine Aquifer (defined as the aquifer unit at the elevation interval from approximately -80 to -230 ft MSL). While the nature of the groundwater constituents as defined in Section 2.1 do not suggest the presence of a single distinct plume, the information in Section 2.1 provides a basis for setting the context under which a remediation approach must function. Thus, the remediation alternatives will target an overall reduction in the current vinyl chloride concentrations to meet the remediation objective within the treatment volume identified in Section 2.1 and to prevent vinyl chloride from impacting the water quality of the City of Plaquemine water supply.

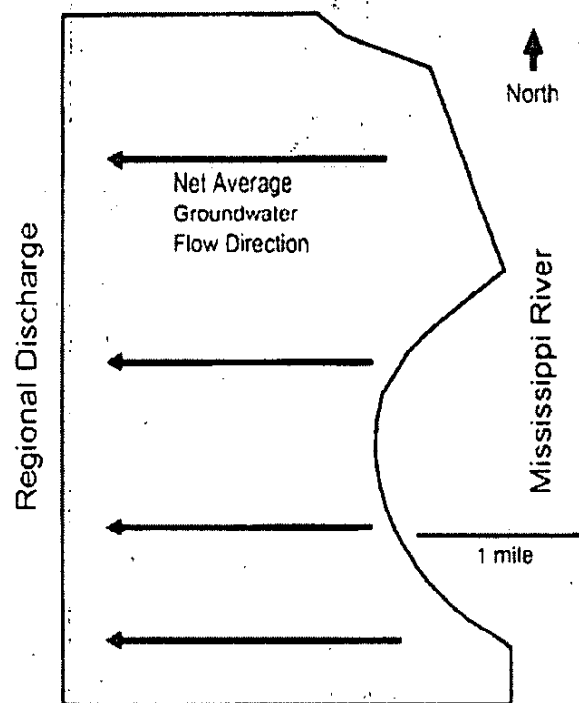


Figure 2. Plan view conceptual model of the Plaquemine Aquifer in the remediation study area.

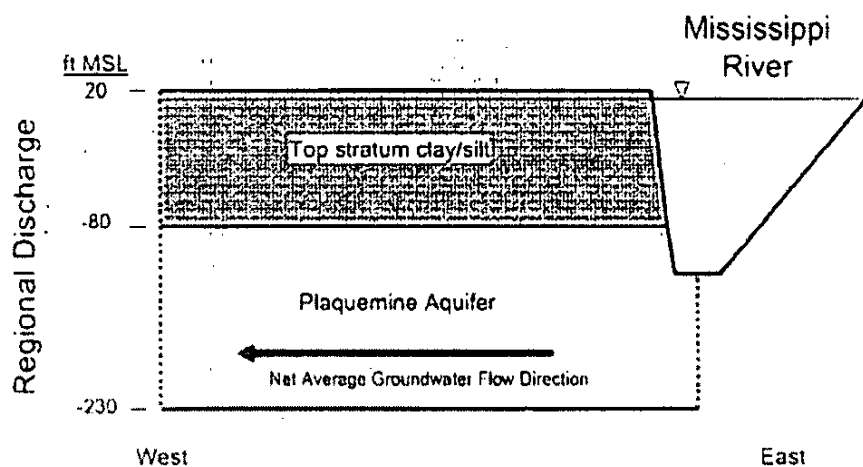


Figure 3. Cross-section of the conceptual model (not to scale). Maximum river depth between river mile 208 and 214 in the bend just north of the City of Plaquemine is approximately 137 ft measured from the Low Water Reference Plane (U.S. Army Corps of Engineers 2006).

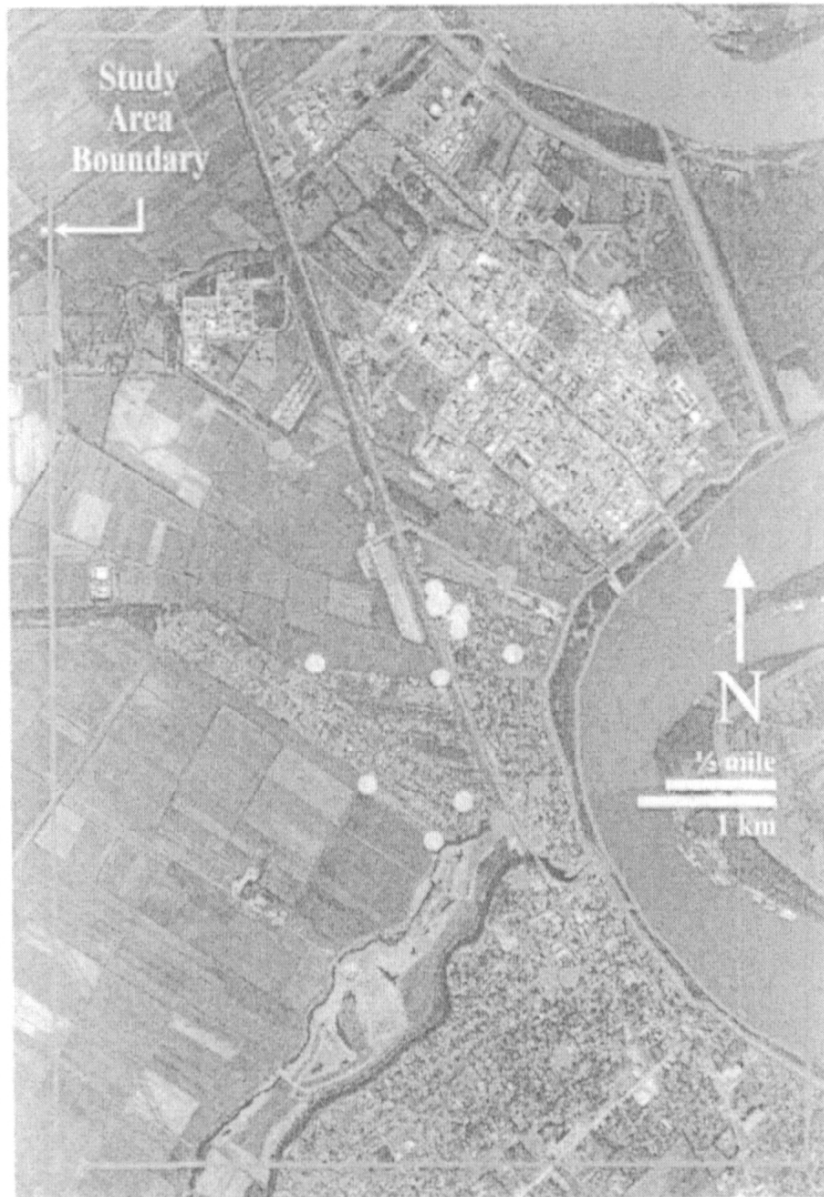


Figure 4 Vinyl chloride concentrations measured in 2006/2007. Yellow dots indicate sample locations at which the maximum concentrations of vinyl chloride in 2006/2007 (up through January 22, 2007, the most current analytical data available at the time of this report) are above the MCL of 2 ppb. Blue dots indicate sample locations in which the maximum concentrations of vinyl chloride in 2006/2007 are below the MCL.

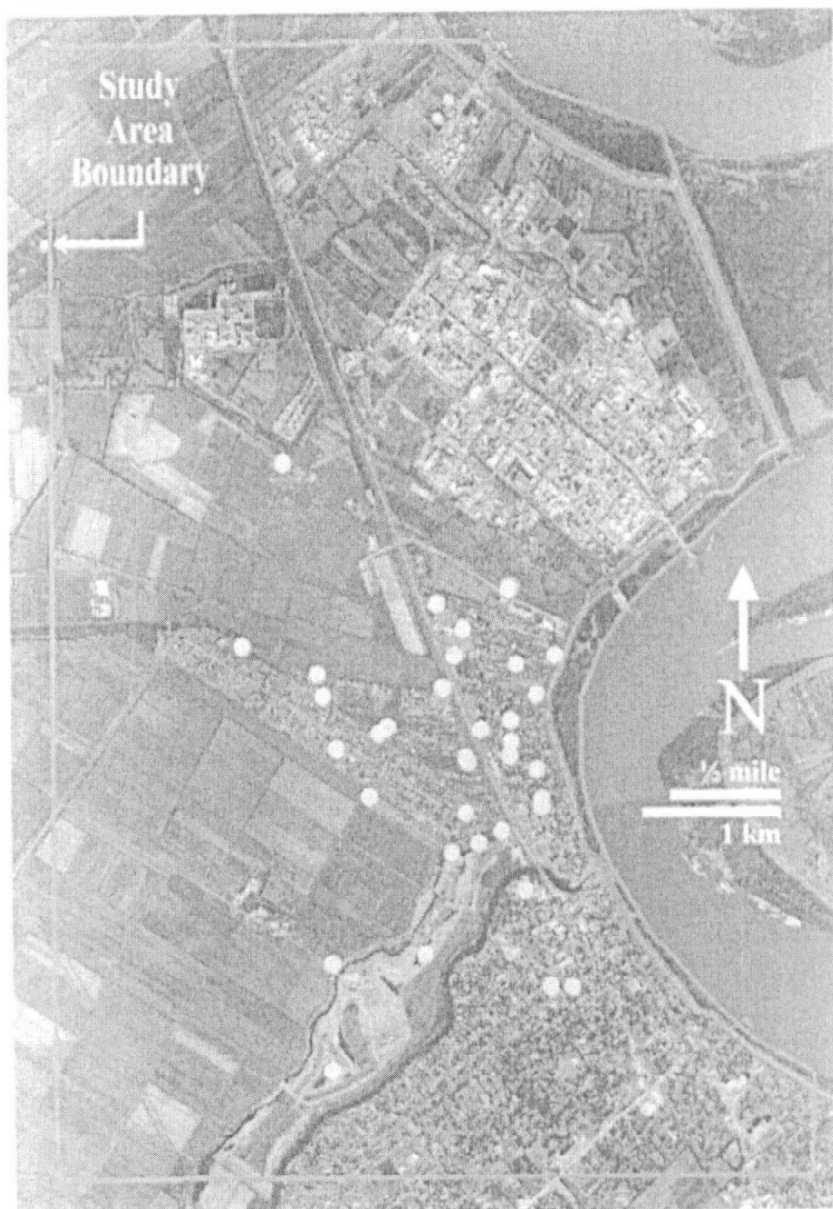


Figure 5 Distribution of arsenic data from filtered groundwater samples (June 29, 2001 through January 22, 2007). Yellow dots are locations where concentrations are above the 10 ppb MCL for arsenic and blue dots show locations below the MCL. Throughout most of the remediation study area, dissolved arsenic data indicate concentrations above the MCL.

### 3.0 Potential Remediation Methods

Potentially applicable remediation methods (Appendix C) were identified based on a review of technical literature, environmental technology databases (e.g., EPA resources), and Battelle's experience for remediation methods that have been used or tested to remediate vinyl chloride at other sites. The categories listed in Table 1 were defined based on the types of remediation methods identified in the review. This listing provided the starting point for evaluating remedial alternatives for application to the Plaquemine Aquifer. The potential remediation methods were reviewed to determine if they were applicable for the environmental setting in the remediation study area based on the appropriate site and contaminant conditions. Remediation methods found to be potentially applicable for the remediation study were then evaluated in accordance with the criteria outlined in the Louisiana Administrative Code, Title 33, Part VI, Section 509, as appropriate. Scoping calculations were conducted as needed to define the scale of infrastructure and quantities of reagents required for each method.

Table 1. Methods potentially applicable to remediation of vinyl chloride.

General Category	Technology Category
Containment	Physical Containment <ul style="list-style-type: none"> <li>• Slurry Walls</li> <li>• Grout Curtain</li> <li>• Sheet Piling</li> </ul> Hydraulic Control
Removal, Treatment, and Disposal	Excavation (with a wide variety of treatment and disposal options)
No Action	Not a technology
Institutional Controls	Not a technology
Monitored Natural Attenuation	Monitored Natural Attenuation (MNA)
Ex Situ Treatment	Pump and Treat <ul style="list-style-type: none"> <li>• Air stripping</li> <li>• Chemical treatment</li> <li>• Biological treatment</li> </ul>
In Situ Treatment	Chemical Oxidation
	Reduction by Zero-Valent Iron
	Air Sparging
	In-Well Air Stripping
	Phytoremediation
	Aerobic Bioremediation <ul style="list-style-type: none"> <li>• Biosparging</li> <li>• Direct microbial-catalyzed oxidation from injected dissolved oxygen</li> <li>• Aerobic Co-metabolism</li> <li>• Injection of long-duration oxygen source (e.g., an oxygen release agent)</li> </ul>
	Anaerobic Bioremediation <ul style="list-style-type: none"> <li>• Soluble substrate</li> <li>• Injection of long-duration substrate (e.g., a non-aqueous substrate such as vegetable oil)</li> </ul>
	In Situ Thermal Treatment <ul style="list-style-type: none"> <li>• Electrical Resistance Heating</li> <li>• Steam Heating</li> <li>• Conductive Heating</li> </ul>
	Permeable Reactive Barriers <ul style="list-style-type: none"> <li>• Zero-Valent Iron</li> <li>• Aerobic Biobarrier (e.g., injection of long-duration oxygen source as a barrier)</li> <li>• Anaerobic Biobarrier (e.g., injection of long-duration substrate as a barrier)</li> </ul>

## 4.0 Screening

### 4.1 Initial Review of Technologies

Potential remediation methods were evaluated to eliminate those methods that are not appropriate for application in the environmental setting of the vinyl chloride contamination within the remediation study area. Table 2 lists the remediation methods/technology categories eliminated in this initial review and the reason they were eliminated from further consideration.

**Table 2. Remediation methods eliminated in the initial review of potential remediation methods.**

Method/Technology Category	Reason
No Action	This option does not prevent exposure to the groundwater and does not provide a means to monitor contamination and assess reduction of vinyl chloride in the aquifer.
Institutional Controls	This option can prevent exposure, but does not provide a means to monitor contamination and assess reduction of vinyl chloride in the aquifer.
Containment	Because the remediation objective is to reduce vinyl chloride concentrations in the aquifer, containment technologies are not applicable for the remediation study.
Removal, Treatment, and Disposal	Removal, treatment, and disposal technologies are targeted at shallow contamination only and, therefore, are not applicable for the remediation study.
Air Sparging	This option is not appropriate for confined aquifers – extraction of vapors is not possible and spreading of contamination may occur due to lateral movement of air bubbles.
In-Well Air Stripping	This option requires sufficient vadose zone thickness to separate air/contaminants from water and provide hydraulic head for re-injection. Also, iron oxidized by air stripping during air lift pumping would be problematic for the direct water re-injection used in in-well air stripping.
Phytoremediation	This option is not appropriate because the contamination is too deep.
Biosparging	This option is not appropriate for confined aquifers – extraction of vapors is not possible and spreading of contamination may occur due to lateral movement of air bubbles.
In Situ Thermal Treatment <ul style="list-style-type: none"> <li>Electrical Resistance Heating</li> <li>Steam Heating</li> <li>Conductive Heating</li> </ul>	This option is not appropriate for confined aquifers with dissolved phase contamination – extraction of vapors is not possible.
Permeable Reactive Barriers <ul style="list-style-type: none"> <li>Zero-Valent Iron</li> <li>Aerobic Biobarrier (e.g., injection of long-duration oxygen source as a barrier)</li> <li>Anaerobic Biobarrier (e.g., injection of long-duration substrate as a barrier)</li> </ul>	Trenching is not possible to support these options. The options do not provide a volumetric treatment. No specific location for application of these options is identified due to the disperse nature of the contamination (e.g., typically these options are deployed to reduce contaminant flux from a source area or to protect a receptor from contamination).



## 4.2 Screening of Remedial Alternatives

Table 3 shows the remedial alternatives considered for the screening. Where needed to support screening, scoping calculations were utilized to define the scale of infrastructure and quantities of reagents required for implementing a remedial alternative. Screening of these remedial alternatives was conducted in accordance with the criteria outlined in the Louisiana Administrative Code, Title 33, Part VI, Section 509, as appropriate. Section 509 provides that the technologies first be evaluated with respect to effectiveness (509 C.2.a). If a technology can be effective, it is then evaluated with respect to technical and administrative implementability (509 C.2.b) and whether it may ultimately prove to be technically and administratively infeasible to implement (509 C.2.c). Technologies not eliminated based on these criteria are evaluated based on relative cost (509 C.2.d) and for regulatory requirements (509 C.2.e). However, even if specific remedial options were eliminated based on the screening criteria in Section 509 C.2.a-c, information on relative cost (C.2.d) (where a reasonable basis for estimation of cost exists) as well as regulatory requirements (C.2.e) is nonetheless presented and discussed. The process used for evaluating remedial options is consistent with 40 CFR 300 and related guidance under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA 1980; EPA 1988, 2000a). The following sections describe the scoping calculations and associated screening evaluation. A discussion of remediation parameter values used in the calculations can be found in Appendix D.

Table 3. Remedial alternatives considered in the screening.

General Category	Technology Category
Monitored Natural Attenuation	Monitored Natural Attenuation (MNA)
Ex Situ Treatment	Pump and Treat
In Situ Treatment	Chemical Oxidation
	Reduction by Zero-Valent Iron
	Aerobic Bioremediation
	<ul style="list-style-type: none"> <li>• Direct microbial-catalyzed oxidation from injected dissolved oxygen</li> <li>• Aerobic Co-metabolism</li> <li>• Injection of long-duration oxygen source (e.g., an oxygen release agent)</li> </ul>
	Anaerobic Bioremediation
	<ul style="list-style-type: none"> <li>• Soluble substrate</li> <li>• Injection of long-duration substrate (e.g., a non-aqueous substrate such as vegetable oil)</li> </ul>

### 4.2.1 Monitored Natural Attenuation

Monitored Natural Attenuation (MNA) is a remedy defined by the EPA Office of Solid Waste and Emergency Response (OSWER) in "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites" (OSWER Directive 9200.4-17P; EPA 1999). The OSWER MNA Directive defines natural attenuation processes included in an MNA approach as follows:

*The "natural attenuation processes" that are at work in such a remediation approach [MNA] include a variety of physical, chemical, or biological processes that, under favorable*

*conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These in situ processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants.*

MNA is an accepted remediation method implemented at numerous sites across the U.S. (e.g., see the following compilations of data from multiple field sites: Aronson and Howard 1997; Saleem 1999; Suarez and Rifai 2004; McGuire et al. 2004). Use of natural processes with no significant energy requirements and the associated negative environmental impact of energy use (e.g., green house gases) are important benefits of MNA. Other key benefits cited for MNA compared to other remedies include implementation with minimally intrusive activities, no extraction and handling of large quantities of contaminated media such that lesser volumes of remediation waste are generated, reduced risk of exposure to contaminants or other hazards associated with remediation during construction and operation, reduced potential for cross-media transfer of contaminants, reduced disturbances to ecological receptors, and remediation based on environmentally friendly in situ processes (EPA 1999).

Natural attenuation of vinyl chloride in the Plaquemine Aquifer is likely occurring via several mechanisms. Regimented monitoring during MNA implementation would further define the specific natural attenuation processes. Biologically mediated degradation of vinyl chloride relevant to the Plaquemine Aquifer has been documented, and existing information suggests that several potential biological natural attenuation processes occur within the Plaquemine Aquifer. Processes present may include: (1) degradation of vinyl chloride through direct aerobic metabolism when dissolved oxygen is present (Hartmans and de Bont 1992); (2) degradation of vinyl chloride under reduced geochemical conditions by reductive dechlorination (DeBruin et al. 1992; Freedman and Gossett 1989); (3) coupled degradation of vinyl chloride to anaerobic respiration processes, such as iron reduction, under reduced geochemical conditions (Bradley and Chapelle 1997); and (4) when oxygen and methane are present, co-metabolic degradation process using monooxygenase enzymes produced for consumption of methane (e.g., Chang and Alvarez-Cohen 1996). The relative rate and extent of these processes would vary at different spatial locations depending on the variation in geochemical conditions observed across the area leading to potentially different types of attenuation at different well locations. For instance, some areas have levels of dissolved oxygen conducive to direct aerobic metabolism of vinyl chloride. In other areas, the geochemical data indicate more reduced conditions that are conducive to anaerobic metabolism or reductive dechlorination. At the intersections of the oxidized and reduced areas, conditions are conducive to aerobic co-metabolism.

Physical mechanisms can also act on vinyl chloride within the aquifer to reduce its concentration. These physical mechanisms include adsorption to aquifer materials, dispersion, and dilution.

The vinyl chloride data set is spatially extensive for the purposes of assessing contamination in the Plaquemine Aquifer. The levels of vinyl chloride vary among wells in the remediation study

area. Eight monitoring wells with vinyl chloride data above 2 ppb (DEQ FF, DEQ HH, DEQ L, DEQ R, DEQ VV, Myrtle Grove 1 and 2, and PZ-34) have vinyl chloride data collected over a relatively long time frame, i.e., from 2001-2006, and, for this reason, were selected to estimate trends in concentration over time. Data from 5 of the 8 wells show a clear decline in vinyl chloride concentration from 2001 through 2006. Of the remaining 3 wells for which the data do not show a decline, two of these three wells are located in close proximity to other wells that do show a decline in vinyl chloride concentrations. Thus, data from these 8 wells show that, on average, vinyl chloride concentrations have declined from 2001 to 2006. While the vinyl chloride concentration has not declined in all of the wells within the remediation study area, the trend of decreasing vinyl chloride concentration at the 8 wells having vinyl chloride data collected over the longest time frame – in addition to the extensive geochemical data indicating that the overall conditions in the aquifer are conducive to MNA – suggests that MNA is a viable remedy and that vinyl chloride concentrations are expected to decrease over time.

To assess whether MNA can meet the remediation objectives within a reasonable timeframe, site-specific data at the 8 wells (identified above) with vinyl chloride concentration data over a 5-year timeframe were evaluated to estimate the remediation timeframe. Though concentrations at individual well locations vary, it is appropriate to utilize average attenuation rates to estimate a remedial time period for evaluation purposes. For these 8 wells, on average, the vinyl chloride concentration has declined by 14.1 ppb (using an average of the highest measured value at each well for 2001 and for 2006 and then computing the difference between these average values), corresponding to a half-life of about 4.6 years (EPA 2002b). The vinyl chloride concentration in the well with the highest historical measured concentration within the remediation study area (well DEQ VV) has varied, but overall, concentrations have declined from 97 to 42.5 ppb over the last 5 years (2001 to 2006, based on the highest measured value at the well in each year), corresponding to a half-life of about 4.2 years (EPA 2002b). For comparison, an exponential regression of all the available data for this well from 2001 through 2006 was conducted (i.e., a best fit to all of the data at well DEQ VV with an equation based on a first-order decay of vinyl chloride as is assumed in estimating a half-life) and a 1.5 year half-life at well DEQ VV was calculated (EPA 2002b). These estimated attenuation rates fall well within the published half-life range from studies that compiled vinyl chloride attenuation rates under anaerobic conditions computed using field data from multiple sites (Aronson and Howard 1997; Saleem 1999; Suarez and Rifai 2004). Thus, the current indications of the trend in vinyl chloride contaminant concentrations indicate that vinyl chloride could be attenuated within a period of 19 to 21 years from a concentration of 42.5 ppb to the MCL (42.5 ppb was the highest vinyl chloride concentration observed in the last groundwater sampling reported in the remediation study data set).

Implementation of an MNA remedy for the Plaquemine Aquifer would use a site-specific approach that meets the requirements of the OSWER MNA Directive (EPA 1999). Appendix E describes how the OSWER requirements can be addressed in this type of approach using the information and monitoring available within the remediation study area. The site-specific approach would be defined in a work plan that would be used to guide implementation of the

MNA remedy. A work plan would be prepared to describe the expected performance of the MNA remedy using the existing contaminant, geochemical, and hydrogeologic data. Based on this estimated performance, a monitoring plan would be described in the work plan to identify the location, analytes, and frequency of analyses that would be necessary to monitor the remedy and to provide sufficient information to evaluate the progress of MNA toward the remediation objectives. Implementation of MNA would involve periodic monitoring of groundwater for the appropriate constituents (e.g., vinyl chloride, cis-1,2-dichloroethene, and indicators of geochemical conditions) with periodic review of the monitoring results, typically a 5-yr review cycle as is used for remediation projects conducted under CERCLA guidance. Elements of the monitoring plan would include demonstrating that natural attenuation processes are occurring, identifying the products from attenuation reactions, monitoring to ensure aquifer conditions remain conducive to attenuation, and verifying that the area of contamination is not expanding or that new contaminant releases are not occurring (see also Appendix E). At the 5-yr review, the monitoring results would be compared to the expected progress of natural attenuation (e.g., expected decrease in vinyl chloride concentration in 5 years) and to the remediation objectives. If the results indicated unacceptable attenuation for a specific portion or portions of the aquifer in the remediation study area, the review would include consideration of potential contingency actions. As described in the OSWER MNA Directive (EPA 1999), a contingency plan would be included in the work plan to identify the process that would be initiated to determine an appropriate action, if necessary, based on the ongoing evaluation of the MNA remedy with respect to the remediation objectives. For instance, the contingency plan may include potential actions such as additional characterization and monitoring, further assessment of treatment options for targeted zones in the aquifer, and laboratory or field treatability tests of potential treatment options. The contingency action would be selected depending on the nature of the monitoring results and would be targeted to that specific portion or portions of the aquifer in the remediation study area where the results indicated that MNA was not working.

#### Assessment

**Effectiveness:** The MNA remedy is expected to be effective in meeting the remediation objectives (Section 2.2) with respect to vinyl chloride contamination. Attenuation processes would not produce hazardous products from vinyl chloride. Attenuation of the cis-1,2-dichloroethene present in the aquifer by reductive dechlorination would produce vinyl chloride, but only at very low concentrations (see Section 2.1.4). As with the active remedies, arsenic in the aquifer is not addressed with natural attenuation.

**Implementability:** MNA is a demonstrated process with full-scale equipment (e.g., for monitoring) and remediation services available. MNA is administratively implementable. No specific permits or waivers are required and no significant administrative issues are presented.

**Infeasible Alternative:** MNA is technically and administratively feasible to implement.

Relative costs and regulatory requirements are not necessary for this evaluation because no other remedy except MNA is retained after screening in accordance with LAC 33:509 C.2. However, even though evaluation of relative costs and regulatory requirements are not necessary pursuant

to section 509, relative cost and regulatory requirements for MNA are presented and discussed below as additional information.

*Relative Cost:* Relative cost is low for MNA because there are no significant cost factors for implementation and operation (Appendix F). Only incremental costs above the cost of the current monitoring well network and aquifer sampling program would be required.

*Regulatory Requirements:* MNA is expected to meet the MCL for vinyl chloride, which is the relevant regulatory requirement for the remediation study.

Based on this screening, MNA is retained as a potential remedy for vinyl chloride contamination in the Plaquemine Aquifer.

#### 4.2.2 Pump-and-Treat

Pump-and-Treat (P&T) systems use wells to extract groundwater from the aquifer. Extraction wells would be installed in locations to capture vinyl chloride contamination. Buried conveyance piping would then move the extracted groundwater to one or more treatment plants where it is then treated as needed to remove contaminants and other constituents in the water to meet discharge requirements. Use of air stripping would be a presumptive treatment to remove vinyl chloride from the water. An arsenic treatment system, if necessary to meet discharge requirements, would be based on EPA guidance describing arsenic treatment technologies (EPA 2002a). Typical treatment would include chemical precipitation for arsenic (EPA 2002a) and air stripping, potentially with activated carbon treatment of vapor emissions for the vinyl chloride (EPA 2005, Suthersan 1999). The chemical precipitation system for arsenic would consist of oxidation pre-treatment, pH adjustment and reagent addition followed by flocculation and clarification systems similar to that used in standard water treatment systems for removal of unwanted inorganic compounds (EPA 2002a). Sludge from the precipitation process would need to be dewatered and disposed in an appropriate landfill as dictated by the concentrations of hazardous compounds in the sludge (e.g., arsenic) (EPA 2002a). For comparison, the size of the treatment system would be about 10 times larger than the current City of Plaquemine water treatment facility. The air stripping operation would be designed to allow vinyl chloride to be removed by volatilization from the extracted water. There are multiple air stripper designs that may potentially be suitable (Suthersan 1999). If necessary, a vapor-phase granular activated carbon unit could remove the contaminants from the air stream by sorption to the carbon. After reaching its capacity for sorption of the contaminant, the carbon would then be disposed in a landfill or regenerated using industry-standard techniques.

The well network design for a P&T system must consider capture of the groundwater in the presence of the regional gradient, effects of water recharge boundaries such as the Mississippi River, and logistical constraints for well and treatment system location (e.g., city infrastructure for electrical power supply and underground utilities and the need for use of private property). Up to 10 or more pore volumes of water may need to be extracted to decrease contaminant concentrations below the remediation goal (Cohen et al. 1997). The number of pore volumes needed depends on the initial concentration, extraction efficiency, and the sorption properties of

the contaminant/aquifer solids. For 10 pore volumes of groundwater extraction, a P&T system for the treatment volume would need to treat approximately 150 billion gallons of water over the duration of remediation. At an extraction flow rate of 2000 gpm and with a well spacing of 2000 ft (Appendix G), a P&T system is expected to require 10 extraction wells located throughout the treatment volume to provide treatment within an estimated 15-year operational period if wells can be installed as discussed below and in locations appropriate for efficient capture of vinyl chloride. Before treatment operations can begin, installation of the P&T wells and treatment system itself would likely require at least 1 to 2 years. Further, this 1 to 2 year installation period would not include the upfront time required to design the system and to obtain permits, and to acquire property and/or access rights or right of ways. Additional schedule delays and performance issues may occur if design locations for the P&T system cannot be used due to property or permit related issues.

The design of a P&T system must be based on analysis of groundwater flow and contaminant capture. At the well locations, a working area would be cleared to accommodate drill rods, drilling waste management, well completion materials, and space for the drill rig. It is expected that a drill rig would require several weeks of operation to complete each well. At each well, a pumping system and 480 volt electrical power supply system would be required. After the well is installed, a series of standard well development procedures would be conducted to prepare the well for long-term pumping. These procedures involve pumping from the well and managing the extracted water, which will initially contain a significant amount of sediment. Each pumping well would require access for maintenance. Water pumped from each well would need to be transported to the treatment plant via piping, and the pipe network may require complex right of ways and/or acquisition of property from landowners. The treatment plant would be constructed at a suitable site. Trenching for installation of conveyance piping would be conducted along the path between each well and the treatment plant. Relatively large diameter pipe would be required due to the high pumping rate with the actual diameter dependent on the flow rate, the length of pipe, and the number of fittings and pipe bends along the route. During trenching and conveyance piping installation, utility interferences and street disturbances would need to be addressed. Once the system is fully constructed, initial testing and potentially continued well development would be required. Following initial operations, cleaning of the system may be required depending on the amount of sediments in the initial water extracted from the wells. Long-term operations would then commence. For operation of the treatment plant, trucking would be used to bring chemicals (e.g., for the precipitation system) to the plant and take waste sludge away from the plant. Periodically (likely on an annual basis), well maintenance for biofouling and mechanical electrical components would be required at each well.

#### Assessment

*Effectiveness:* P&T is likely able to meet the remediation objectives (Section 2.2) with respect to vinyl chloride contamination, but significant difficulties may be incurred due 1) to the proximity to and hydraulic connection with the Mississippi River and 2) the large scale of the treatment. Operation may require extraction of many pore volumes (Cohen et al. 1997). P&T would have minimal impact on long-term groundwater arsenic concentrations due to the presence of arsenic

in the aquifer solids. While P&T will extract and remove arsenic with the groundwater, arsenic on the aquifer solids cannot be effectively extracted and will continue to be released over time into the groundwater.

*Implementability:* P&T is a demonstrated process with full-scale equipment and remediation services available. Administrative implementability of P&T is very difficult due to significant construction and operational issues. Installation of conveyance piping to move contaminated water from the wells to the treatment plant is expected to cross multiple existing utilities, both underground and above ground. Interference with existing buried utilities would require permission outside of the administrative jurisdiction of the environmental regulatory agencies. It is likely that there would be significant difficulty and related schedule delays in obtaining the necessary permits and in acquiring needed property and/or property right of ways. The difficulty is exacerbated by the significant utility disturbances related to the extensive P&T infrastructure that would be required. The well network design to efficiently capture vinyl chloride contamination would require locating wells and conveyance piping in residential areas. Issues with wells, pumping equipment, and conveyance piping locations on, through, or adjacent to private property would need to be identified, addressed, and resolved. Installation of conveyance piping to move contaminated water from the wells to the treatment plant for the network of wells needed in the treatment volume would cross and potentially be installed beneath streets. Disruption of streets and associated disturbances during construction would require permission from the appropriate agencies or government offices. Operation of the P&T system would require conducting and managing the industrial-type activities associated with the system (e.g., well maintenance) within a residential area.

*Infeasible Alternative:* In addition to the considerable difficulties with administrative implementability, technical implementation of P&T is uncertain due to the proximity to and hydraulic connection with the Mississippi River and the large scale of the treatment. Additionally, surface structures or property concerns may not allow installation of wells in preferred well locations and alternate locations may have difficulties with contaminant capture (e.g., capture zones cannot overcome large well spacings) or may require longer treatment times (e.g., if contamination must move a long distance to extraction wells).

Based on this screening, P&T is eliminated from further consideration because it has unacceptable administrative implementation issues and likely will ultimately prove to be both technically and administratively infeasible to implement. Therefore, evaluation of relative costs and regulatory requirements are not necessary in accordance with LAC 33:509 C.2. However, even though evaluation of relative costs and regulatory requirements are not necessary pursuant to section 509, relative cost and regulatory requirements information for P&T are presented and discussed below as additional information.

*Relative Cost:* Relative cost is high for P&T (more than an order of magnitude higher than cost for MNA) because there are significant cost factors for implementation and operation (Appendix

F). Some of these cost factors include large diameter wells for high extraction flow rate, conveyance piping, and a high volume treatment system for VC and arsenic.

*Regulatory Requirements:* P&T can meet the regulatory requirements only if it can be implemented effectively. For the reasons above, P&T is infeasible and cannot be implemented to meet the MCL for vinyl chloride, which is the relevant regulatory requirement for the remediation study.

#### 4.2.3 Chemical Oxidation

This category of technology includes use of strong oxidants such as hydrogen peroxide, Fenton's Reagent, permanganate, persulfate, and ozone. A primary factor in applying chemical oxidation is overcoming the oxygen demand within the aquifer during injection of the oxidant. As oxidant is injected, it quickly reacts with oxidizable materials in the aquifer (including the contaminant). With radial injection flow, the volume of aquifer, and therefore the mass of oxidizable materials associated with aquifer solids increases with the square of the distance from the injection point. As a scoping calculation, oxidant demand was estimated based on the mass of oxidizable material in the aquifer as a function of radial distance from a well and for the total treatment volume (Appendix G). Chemical oxidation has been applied as a targeted treatment for relatively high concentrations of contaminants at a scale that is orders of magnitude smaller than would be necessary for treatment at the scale of the remediation study treatment volume in the Plaquemine Aquifer.

##### Assessment

*Effectiveness:* With the chemical oxidation alternative, there is high uncertainty in meeting the remediation objectives (Section 2.2) with respect to vinyl chloride contamination. Chemical oxidation technology has been proven capable for treating chlorinated solvents only on a small scale.

Arsenic is present as a co-contaminant to vinyl chloride in the aquifer. It is predominantly in the +3 valence state as would be expected under the reduced redox conditions in the aquifer (see Appendix H). Chemical oxidation may reduce arsenic concentrations in the groundwater by oxidizing the arsenic (+3) to arsenic (+5), which partitions to a greater extent onto aquifer solids. This reduction of groundwater arsenic concentration is likely to be only temporary because arsenic would be re-released to the groundwater upon a return to reducing conditions in the aquifer.

*Implementability:* Chemical oxidation is a demonstrated process with full-scale equipment and remediation services available. Administrative implementability is unacceptable for chemical oxidation due to the same type of significant construction and operational issues as were described for the P&T alternative (see Section 4.2.2). In fact, these implementability issues are more problematic with the chemical oxidation alternative because (1) this alternative would require more wells than for P&T, and (2) the oxygen demand analysis shows that extremely large quantities of oxidant would be required (Appendix G).



*Infeasible Alternative:* In addition to the considerable difficulties with administrative implementability, technical implementation of chemical oxidation is highly uncertain at the required scale and considering issues with surface structures or property concerns that do not allow installation of wells in preferred well locations. The system design is sensitive to difficulties with hydraulic control. Because chemicals are being injected into the aquifer for the oxidation process, there is a potential to spread contamination outward from the injection well.

Based on this screening, chemical oxidation is eliminated from further consideration because it has unacceptable administrative implementation issues and likely will ultimately prove to be both technically and administratively infeasible to implement. Therefore, evaluation of relative costs and regulatory requirements are not necessary in accordance with LAC 33:509 C.2. In addition, relative cost for the chemical oxidation remedial option cannot be reasonably estimated because no cost basis exists for application of this technology at the scale that would be required for the remediation study treatment volume in the Plaquemine Aquifer. Further, chemical oxidation could not meet regulatory requirements for the reasons stated above.

#### 4.2.4 Zero-Valent Iron

Emplacement of zero-valent iron particles in the subsurface provides an electron source for reduction (dechlorination) of vinyl chloride. Typically, zero-valent iron is applied as a permeable reactive barrier. Iron particles are injected into the aquifer through a line of wells to form a permeable reactive barrier. The iron particles react with and degrade contaminants as groundwater flows through the permeable reactive barrier. Over time, the ability of the zero-valent iron to degrade contaminants decreases as the iron particles become coated with precipitates and are no longer able to catalyze degradation reactions. Potentially, zero-valent iron could be deployed in a manner more suitable for volumetric treatment. However, for volumetric treatment, the extent to which the iron particles can be distributed is a key issue for consideration. Injection and dispersion of iron into an aquifer 150-ft thick extending over the areal extent of the treatment volume is a scale of application that is orders of magnitude greater than dispersed iron treatment applications conducted to date (GeoSierra 2005). Present technology permits placement of small-scale iron particles from wells to radial distances of about 10-20 ft (GeoSierra 2005). Similarly low radial influences are observed with current applications of emulsified zero-valent iron (Quinn et al. 2005). Thus, wells would need to be placed at intervals on the order of 10s of feet throughout the treatment zone, which would not be practical at the scale of the remediation study treatment volume due to logistical constraints at the surface especially for residential areas and would also require very large quantities of iron particles.

#### Assessment

*Effectiveness:* With the zero-valent iron alternative, there is high uncertainty in meeting the remediation objectives (Section 2.2) with respect to vinyl chloride contamination due to uncertainty in distributing the iron and loss of iron particle reactivity over time. Zero-valent iron technology has been proven capable for treating chlorinated solvents only at a small scale.

*Implementability:* Zero-valent iron is a demonstrated process with full-scale equipment and remediation services available. Administrative implementability is unacceptable for zero-valent iron due to the large number of injection wells (hundreds) that would be needed. With the close well spacing that would be required, it would not be possible to install a system for the treatment volume without significantly infringing on private property or interfering with surface structures.

*Infeasible Alternative:* Based on the small radius of influence for injected zero-valent iron, it is considered to be infeasible for volumetric treatment at the scale of the remediation study. Because there are no smaller, distinct, high-concentration areas within the remediation study area that are more typical of the type of conditions for which zero-valent iron is applied, targeted applications are not relevant for the remediation study.

Based on this screening, zero-valent iron is eliminated from further consideration because it has unacceptable administrative implementation issues and likely will ultimately prove to be both technically and administratively infeasible to implement. Therefore, evaluation of relative costs and regulatory requirements are not necessary in accordance with LAC 33:509 C.2. In addition, relative cost for the zero-valent iron remedial option cannot be reasonably estimated because no cost basis exists for application of this technology at the scale that would be required for the remediation study treatment volume in the Plaquemine Aquifer. Further, zero-valent iron could not meet regulatory requirements for the reasons stated above.

#### **4.2.6 In Situ Aerobic Bioremediation**

For scoping, the in situ aerobic bioremediation considered for implementation was a remediation system to biostimulate direct microbial-catalyzed oxidation of vinyl chloride with injected dissolved oxygen (see discussion in Appendix G). Implementation would be consistent with guidelines described in "Engineered Approaches to In Situ Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications" (EPA 2000b). Treatment would use a groundwater recirculation system to distribute oxygen in the subsurface. Because of the large areal extent of contamination, the aerobic bioremediation system would treat groundwater as it is recirculated through the biologically active zones induced by addition of the oxygen in the aquifer surrounding the injection wells. As such, the timeframe for treatment would be controlled by the timeframe for recirculation and sweeping of the contaminant from the aquifer. The timeframe for treatment would be similar to the timeframe for the P&T system, though somewhat shorter due to the larger number of wells (i.e., 5-15 years). Before treatment operations can begin, installation of the system (wells and conveyance piping) itself would likely require at least 1 to 2 years. Further, this 1 to 2 year installation period would not include the upfront time required to design the system and to obtain permits, and to acquire property and/or access rights or right of ways.

Hydrogen peroxide or pure oxygen injection could provide enough oxygen to overcome the oxygen demand of dissolved compounds. For groundwater recirculation, fouling from reduced iron would need to be addressed through removal of the iron in the aboveground recirculation system prior to re-injection. A permit for re-injection of groundwater would be required. The

required infrastructure for water handling includes extraction wells, iron precipitate removal, transmission piping, hydrogen peroxide storage and injection, and injection wells as specified in the following paragraphs. At each group of recirculation wells, an above ground system would operate to add oxygen to the extracted water, remove iron particles that would precipitate in a filtration apparatus, and convey the water to the injection point.

Based on the well spacing assessment presented in Appendix G, the groundwater recirculation system for in situ aerobic bioremediation would consist of extraction well lines with wells 600 ft apart and an injection well line (two injection wells per extraction well) at a distance of about 2,000 ft from the extraction well line. Extraction wells would operate at 2,000 gpm. Extracted water would be aerated through direct injection of hydrogen peroxide to obtain nominally 20 mg/L of dissolved oxygen. Iron precipitate would be removed by filtration. The oxygenated water would then be piped to the injection wells. The process is estimated to generate approximately 27 kg of iron sludge per extraction well per day of operation. Hydrogen peroxide consumption is estimated to be 370 kg per extraction well per day of operation. The well network would include an estimated 33 extraction wells and 66 injection wells to cover the treatment volume and to maintain hydraulic control of the groundwater during treatment. Because water is being injected into the aquifer to add the oxygen needed for the aerobic bioremediation process, there is a potential to spread contamination outward from the injection well. Therefore, to prevent spreading of contamination, a relatively large number of wells are needed to maintain control of the water such that the injected water is effectively captured by nearby extraction wells.

#### Assessment

*Effectiveness:* With the in situ aerobic bioremediation alternative, there is moderate to high uncertainty in meeting the remediation objectives (Section 2.2) with respect to vinyl chloride contamination. Aerobic bioremediation relies on effective distribution of oxygen and the activity of appropriate bacteria. Biological degradation processes would not produce hazardous products.

Arsenic is present as a co-contaminant to vinyl chloride in the aquifer. It is predominantly in the +3 valence state as would be expected under the reduced redox conditions in the aquifer (see Appendix H). Aerobic bioremediation may also reduce arsenic concentrations in the groundwater by oxidizing the arsenic (+3) to arsenic (+5), which partitions to a greater extent onto aquifer solids. This reduction of groundwater arsenic concentrations is likely to be only temporary because arsenic would be re-released to the groundwater upon a return to reducing conditions in the aquifer.

*Implementability:* In situ aerobic bioremediation is a demonstrated process with full-scale equipment and remediation services available. Administrative implementability is unacceptable for in situ aerobic bioremediation due to the same type of significant construction and operational issues as were described for the P&T alternative (see Section 4.2.2). These implementability issues are more problematic with the in situ aerobic bioremediation alternative

because this alternative requires more wells and more conveyance piping to support the necessary recirculation of groundwater.

*Infeasible Alternative:* In addition to the considerable difficulties with administrative implementability, technical implementation of in situ aerobic bioremediation is uncertain at the required scale of application, including difficulties with surface structures or property concerns that do not allow installation of wells in preferred well locations. The system design is sensitive to difficulties with hydraulic control, which would potentially cause spreading of contamination during oxygen injection if contaminated groundwater is pushed outside the capture zone of the extraction wells by the water injected at the injection wells to carry the oxygen into the aquifer.

Based on this screening, in situ aerobic bioremediation is eliminated from further consideration because it has unacceptable administrative implementation issues and likely will ultimately prove to be both technically and administratively infeasible to implement. Therefore, evaluation of relative costs and regulatory requirements are not necessary in accordance with LAC 33:509 C.2. However, even though evaluation of relative costs and regulatory requirements are not necessary pursuant to section 509, relative cost and regulatory requirements information for in situ aerobic bioremediation are presented and discussed below as additional information.

*Relative Cost:* Relative cost is high for aerobic bioremediation, at least an order of magnitude higher than the cost for MNA, because there are significant cost factors for implementation and operation (Appendix F). Some of these cost factors include numerous large diameter wells for high extraction/injection flow rate and conveyance piping.

*Regulatory Requirements:* In situ aerobic bioremediation can meet the regulatory requirements only if it can be implemented effectively. For the reasons above, in situ aerobic bioremediation is infeasible and therefore cannot be implemented to meet the MCL for vinyl chloride, which is the relevant regulatory requirement for the remediation study.

#### **4.2.6 In Situ Anaerobic Bioremediation**

For scoping, the in situ anaerobic bioremediation considered for implementation was a remediation system to biostimulate reductive dechlorination of vinyl chloride with a soluble substrate (e.g., molasses) (see discussion in Appendix G). Implementation would be consistent with guidelines described in "Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents" (AFCEE 2004). A groundwater recirculation system would be used to distribute a substrate to attempt to enhance reductive dechlorination of vinyl chloride. Because of the large areal extent of contamination, the anaerobic bioremediation system would treat groundwater as it is recirculated through the biologically active zones induced by addition of the substrate in the aquifer surrounding the injection wells. As such, the timeframe for treatment would be controlled by the timeframe for recirculation and sweeping of the contaminant from the aquifer. Thus, the timeframe for treatment would be similar to the timeframe for the P&T system, though somewhat shorter due to the larger number of wells (i.e., 5-15 years). Before treatment operations can begin, installation of the system (wells and conveyance piping) itself

would likely require at least 1 to 2 years. Further, this 1 to 2 year installation period would not include the upfront time required to design the system and to obtain permits, and to acquire property and/or access rights or right of ways.

A treatability study is required to select the best substrate to stimulate more rapid degradation of vinyl chloride. A permit for re-injection of groundwater would be required. The required infrastructure for water handling includes extraction wells, transmission piping, substrate storage and injection, and injection wells as specified in the following paragraphs. At each group of recirculation wells, an above ground system would operate to add substrate to the extracted water and convey the water to the injection point.

Based on the well spacing assessment presented in Appendix G, the groundwater recirculation system for in situ anaerobic bioremediation would consist of extraction well lines with wells 600 ft apart and injection well lines (two injection wells per extraction well) at a distance of about 2,000 ft from the extraction well line. Extraction wells would operate at 2,000 gpm. Extracted water would be amended with the substrate to obtain about 250 mg/L. This estimate for the substrate concentration was based on using molasses and providing sufficient substrate to reduce the sulfate present and to generate the anaerobic conditions and hydrogen needed to support vinyl chloride dechlorination. Substrate consumption is estimated to be about 2,700 kg per extraction well per day of operation. The well network would include an estimated 33 extraction wells and 66 injection wells to cover the treatment volume and to maintain hydraulic control of the groundwater during treatment. Because water is being injected into the aquifer to add the substrate needed for the anaerobic bioremediation process, there is a potential to spread contamination outward from the injection well. Therefore, to prevent spreading of contamination, a relatively large number of wells are needed to maintain control of the water such that the injected water is effectively captured by nearby extraction wells.

#### Assessment

*Effectiveness:* With the in situ anaerobic bioremediation alternative, there is moderate to high uncertainty in meeting remediation objectives (Section 2.2) with respect to vinyl chloride contamination. Anaerobic bioremediation relies on effective distribution of substrate and activity of appropriate bacteria. Biological degradation processes for vinyl chloride would not produce hazardous products. Biological degradation of DCE could produce vinyl chloride, but only at low concentrations (see section 2.1.4).

Arsenic is present as a co-contaminant to vinyl chloride. It is predominantly in the +3 valence state as would be expected under the reduced redox conditions in the aquifer (see Appendix H). Anaerobic bioremediation may increase the arsenic concentration in the groundwater by reduction of iron oxide coatings on the aquifer solids that contain arsenic.

*Implementability:* In situ anaerobic bioremediation is a demonstrated process with full-scale equipment and remediation services available. Administrative implementability is unacceptable for in situ aerobic bioremediation due to the same type of significant construction and

operational issues as were described for the P&T alternative (see Section 4.2.2). These implementability issues are more problematic with the in situ anaerobic bioremediation alternative because this alternative requires more wells and more conveyance piping to support the necessary recirculation of groundwater.

*Infeasible Alternative:* In addition to the considerable difficulties with administrative implementability, technical implementation of in situ anaerobic bioremediation is uncertain at the required scale of application, including difficulties with surface structures or property concerns that do not allow installation of wells in preferred well locations. The system design is sensitive to difficulties with hydraulic control, which would potentially cause spreading of contamination during substrate injection if contaminated groundwater is pushed outside the capture zone of the extraction wells by the water injected at the injection wells to carry the substrate into the aquifer.

Based on this screening, in situ anaerobic bioremediation is eliminated from further consideration because it has unacceptable administrative implementation issues and likely will ultimately prove to be both technically and administratively infeasible to implement. Therefore, evaluation of relative costs and regulatory requirements are not necessary in accordance with LAC 33:509 C.2. However, even though evaluation of relative costs and regulatory requirements are not necessary pursuant to section 509, relative cost and regulatory requirements information for in situ anaerobic bioremediation are presented and discussed below as additional information.

*Relative Cost:* Relative cost is high for anaerobic bioremediation, at least an order of magnitude higher than the cost for MNA, because there are significant cost factors for implementation and operation (Appendix F). Some of these cost factors include numerous large diameter wells for high extraction/injection flow rate and conveyance piping.

*Regulatory Requirements:* In situ anaerobic bioremediation can meet the regulatory requirements only if it can be implemented effectively. For the reasons above, in situ anaerobic bioremediation is infeasible and therefore cannot be implemented to meet the MCL for vinyl chloride, which is the relevant regulatory requirement for the remediation study.

#### **4.2.7 Results of Evaluation Based on Scoping Calculations**

Scoping calculations indicated that all of the potential remedial alternatives, with the exception of MNA, are either (1) not effective (LAC 33: VI. 509 C.2.a), (2) not implementable (LAC 33: VI. 509 C.2.b), or (3) not feasible (LAC 33: VI. 509 C.2.c), and should thus be eliminated from further consideration in the remediation study. In addition, the relative cost estimates show that costs for active remedies are grossly (e.g., an order of magnitude) higher than the cost of the MNA remedy.

## 5.0 Conclusions

The remediation study was prepared pursuant to the *Cooperative Agreement between the State of Louisiana Department of Environmental Quality and The United States Environmental Protection Agency and The Dow Chemical Company in the Matter of the Plaquemine Aquifer*. The scope of the remediation study was to evaluate (1) the long-term need for remediation of the Plaquemine Aquifer and (2) feasible remediation options. The study included consideration of the four (4) remediation options enumerated in the Cooperative Agreement: monitoring and natural attenuation, chemical injection, biostimulation, and no further action.

The evaluation results indicate that active remedies are not feasible. Active measures would require large-scale pumping wells and/or surface infrastructure in populated areas. Interference from existing utilities, residences, and other facilities present significant challenges for construction, and construction would cause considerable disruption of commercial/residential activities. An active remediation operation would require significant industrial-type activities in residential areas. Further, the active remedies for vinyl chloride in the remediation study area will not effectively reduce the excessive levels of arsenic to at or below the MCL. In fact, some active remedies for vinyl chloride may increase the arsenic concentrations. The no further action alternative was eliminated in the initial review of potential remediation methods.

Evaluation of the EPA indicators of the potential for natural attenuation of the vinyl chloride contamination in the aquifer found conditions favorable for vinyl chloride degradation and the data suggest rates of degradation suitable for an MNA remedy. It is reasonable to expect that natural attenuation processes will reduce the vinyl chloride contamination to levels at or below the MCL in the Plaquemine Aquifer. A site-specific approach for MNA could be applied and the associated periodic monitoring would be an effective mechanism to ensure that the vinyl chloride contamination does not expand and does not impact the City of Plaquemine water supply. Thus, MNA is the recommended approach to the contamination.

In summary, this assessment reveals that active vinyl chloride remediation is not an appropriate option in the remediation study area. The proper and recommended approach is a Monitored Natural Attenuation remedy that includes continued monitoring to ensure that the extent of low-level vinyl chloride contamination does not expand.

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## Appendix A

### Hydraulic Conceptual Model

In the area of the remediation study, the dominant factor controlling the groundwater flow system in the Plaquemine Aquifer is its hydraulic interaction with the Mississippi River. The groundwater flow within this portion of the Plaquemine Aquifer was quantified by Naymik (2004) based on site-specific data such as hydraulic head, river stage, and aquifer property data collected from within the remediation study area. These data include analytical data collected from the sentinel wells, U. S. Environmental Protection Agency (EPA) wells 1-5, and private wells in North Plaquemine that comprised the EPA/Louisiana Department of Environmental Quality (LDEQ) Semi-Annual Testing, and data collected by The Dow Chemical Company for the South Perimeter Groundwater Study. Hydraulic properties associated with this flow system are summarized in Table A-1. The average hydraulic conditions for use in this study were selected based on the average gradient and direction for a yearly cycle at six locations in the remediation study area (Table A-2). More recent water level data collected as part of the South Perimeter Groundwater Study are consistent with the groundwater flow information presented herein.

Table A-1. Hydraulic properties used to describe the Plaquemine Aquifer in the remediation study.

Hydraulic Property	Value	Comment	Reference
Horizontal hydraulic conductivity	430 ft/d	Value derived from pump test analysis in Naymik (2004)	Naymik 2004
Vertical hydraulic conductivity	43 ft/d	Estimated as one tenth of the horizontal hydraulic conductivity	Estimated based on information in Freeze and Cherry 1979
Porosity	0.3	Value used in Naymik (2004) as a standard estimate within the range reported for sandy and gravely aquifers in Freeze and Cherry (1979)	Naymik 2004; Freeze and Cherry 1979
Bulk density	1.85 kg/L	Value calculated using the selected porosity and a solid density of 2.65 kg/L (Freeze and Cherry 1979)	Calculated
Storage coefficient	0.0007	Value derived from pump test analysis in Naymik (2004)	Naymik 2004
Linear equilibrium partitioning coefficient for vinyl chloride	0.23 L/kg-soil	Average of estimated values from Naymik (2004)	Naymik 2004

**Table A-2. Summary of groundwater flow in the remediation study area based on remediation study area data from September 23, 2002 through September 22, 2003.**

Location	Average Gradient <sup>(a)</sup>	Direction of Gradient <sup>(a)</sup> (degrees)
Block 66, Dow Plaquemine Operations	0.000413	268
Block 49, Dow Plaquemine Operations	0.000365	240
Block 6, Dow Plaquemine Operations	0.000237	262
Lighthouse Road Site	0.000776	267
Well DEQ VV	0.00044	262
Myrtle Grove Well	0.000287	314
Average	0.00042	269
(a) Calculated based on the data presented in Naymik (2004). A direction of zero degrees is map north and degrees progress clockwise such that 269 degrees corresponds to a flow almost due west.		

The water supply wells located in the City of Plaquemine were in operation from 1952 until 1967. Since 1967, water has been delivered in a pipeline from wells located near the Port Allen Lock, outside the remediation study area, and this Port Allen water has been, and remains, the primary water supply for the City of Plaquemine. From 1967 through 1999, the wells in the City of Plaquemine operated only during infrequent emergency events. Limited, short-duration pumping of these wells for regular maintenance operations occurred from the year 2000 through May 16, 2004. Since May 17, 2004, city wells operated routinely on a periodic basis as a supplemental source of water to the primary Port Allen water source. The hydraulic conceptual model included an assessment of groundwater flow direction during two time intervals: (1) when the City of Plaquemine water supply wells were pumping and (2) when there was no significant pumping from the City of Plaquemine water supply wells. Hydraulic head data for the Mississippi River and at the South Perimeter Groundwater Study monitoring locations are available during the time period of May 17, 2004 through January 31, 2005 (a period of 37 weeks when the City of Plaquemine wells were pumping routinely) and were used to estimate the hydraulic head contours for the remediation study area using the method described by Naymik (2004). As a comparison over the same duration (37 weeks) and same seasonal period, hydraulic head contours for the remediation study area were also estimated for the time interval from May 19, 2003 through February 2, 2004, representing conditions when there was no significant pumping of the City of Plaquemine water supply wells (i.e., only limited, short-duration pumping for maintenance operations). Note that the actual start and end days for the two intervals are slightly different due to the date that measurements were taken each year. Figure A-1 shows the Mississippi River stage during these two time intervals. These time intervals are generally during lower river stage conditions where the impact of any pumping in the aquifer would be the greatest.

To assess the impact of pumping at the City of Plaquemine water supply wells, the flow direction was estimated at a series of points along the southern portion of the area where some monitoring wells show contamination by vinyl chloride or by cis-1,2-dichloroethene (DCE) at concentrations greater than 3 ppb (i.e., concentrations of DCE where under specific conditions could produce vinyl chloride at or above 2 ppb – see Section 2.1.4). The flow direction analysis was conducted by vector analysis of the flow direction based on weekly hydraulic head contours that were developed using the water level data from the South Perimeter Groundwater Study and the method described by Naymik (2004). Figure A-2 shows the location of the points used in the flow direction analysis in relation to the monitoring locations where weekly water-level data are available as part of the South Perimeter Groundwater Study. Note that the locations selected for the flow direction analysis are surrounded by other water-level data points so that the hydraulic head contours in this area are interpolated between data points, not extrapolated outside the available data points. Figure A-3 shows the results of the flow direction analysis. The flow direction does not change significantly when comparing the pumping and no-pumping conditions. Based on this analysis, it is not expected that vinyl chloride contamination or DCE at concentrations with the potential to produce vinyl chloride above 2 ppb (see section 2.1.4) will move toward the City of Plaquemine water supply wells, even if they are continuously pumping.

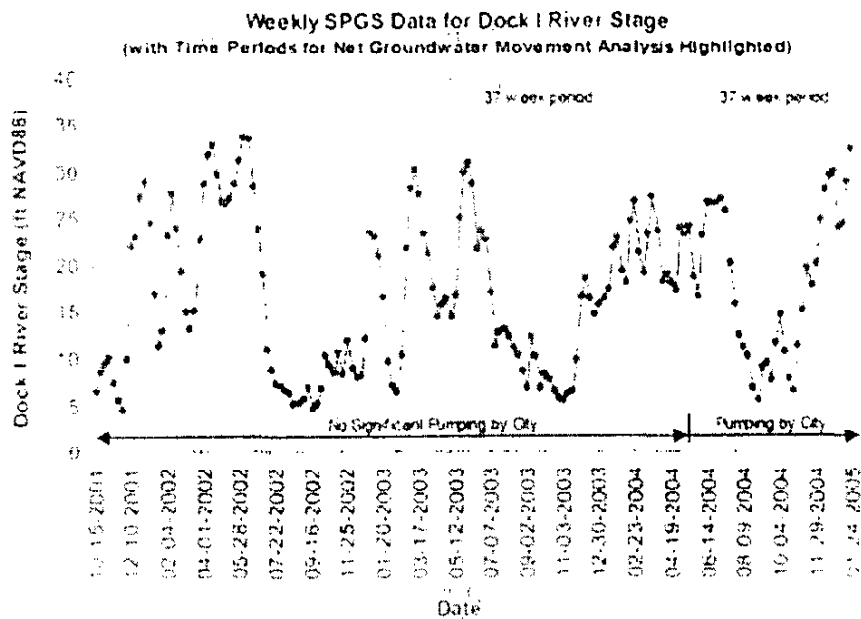


Figure A-1 Mississippi River stage and time periods used to compare groundwater flow direction with and without the influence of pumping by the City of Plaquemine

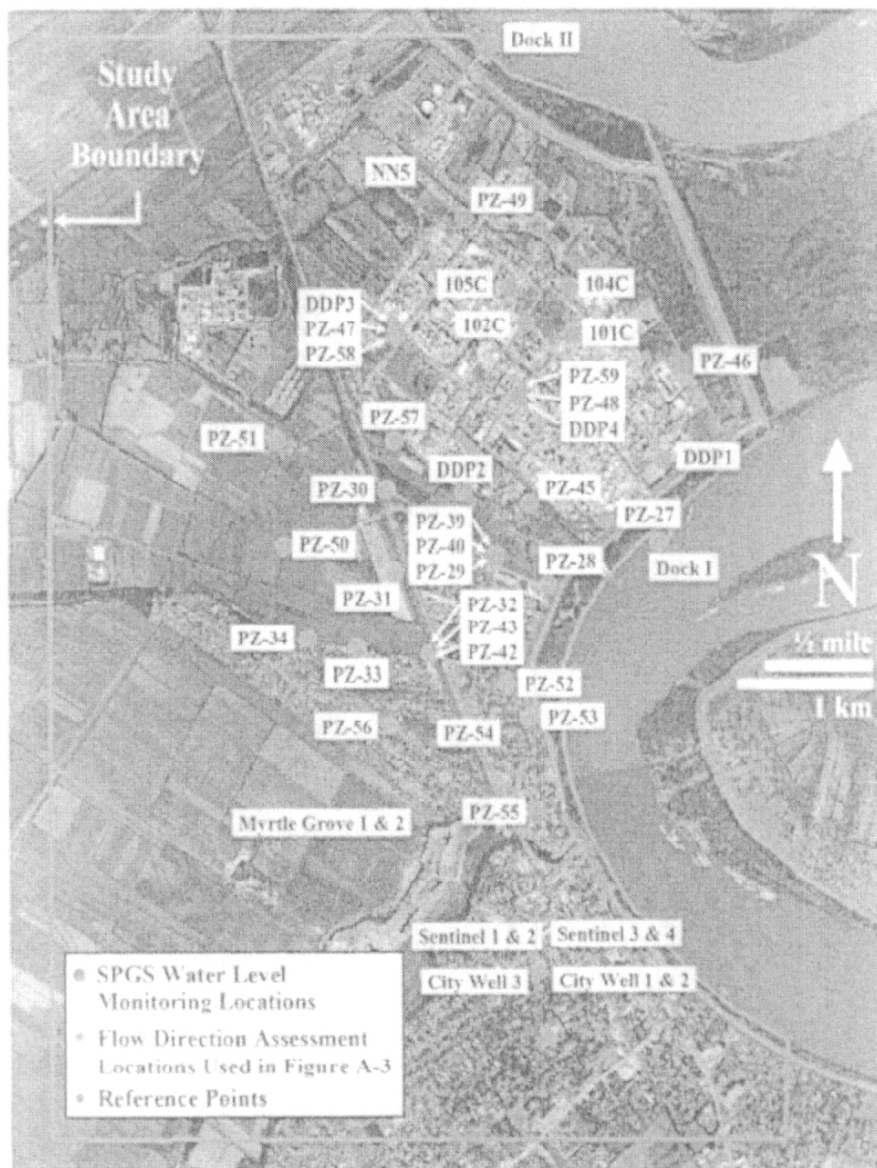


Figure A-2 Location of points used for flow direction analysis (red dots), monitoring locations where weekly water level data are available from the South Perimeter Groundwater Study (green dots), location of other wells of interest (light blue dots)

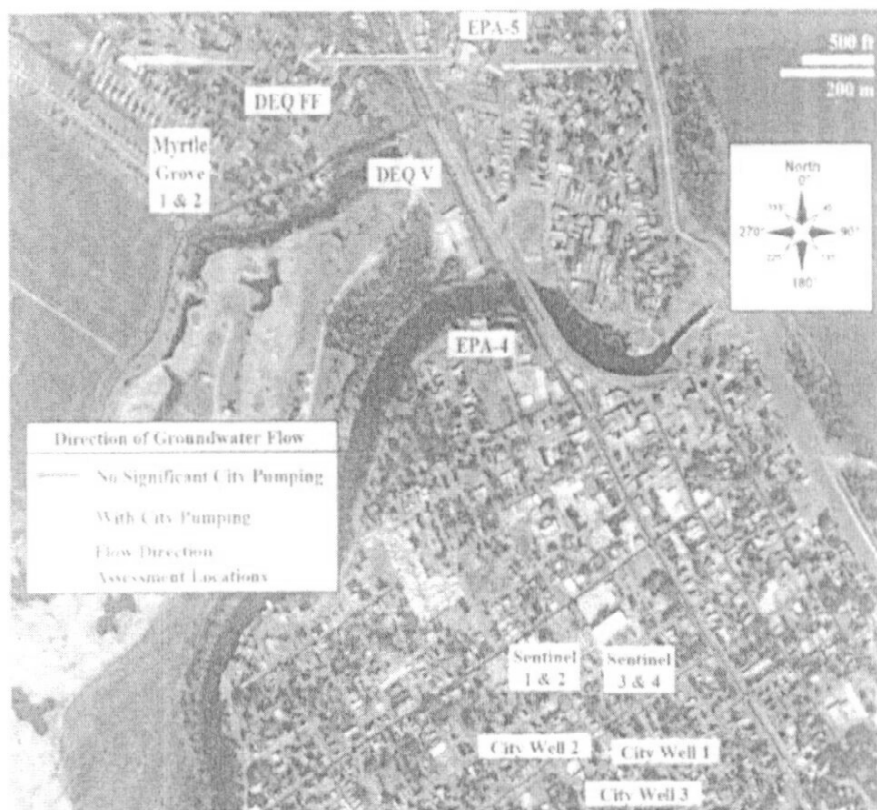


Figure A-3 Results of flow direction analysis at three points along the southern portion of the area where some monitoring wells show contamination by vinyl chloride or by DCE at concentrations greater than 3 ppb (i.e., concentrations of DCE where under specific conditions could produce vinyl chloride at or above 2 ppb – see Section 2.1.4). The flow direction analysis was conducted by vector analysis of the flow direction based on weekly hydraulic head contours from the water level data from the South Perimeter Groundwater Study using the method described by Naymik (2004). The flow direction does not change significantly when comparing pumping (yellow arrows) and no-pumping (green arrows) conditions over the same duration and same seasonal period (see Figure A-1). Based on this analysis, it is not expected that vinyl chloride contamination or DCE at concentrations with the potential to produce vinyl chloride above 2 ppb (see Section 2.1.4) will move toward the City of Plaquemine water supply wells even if they are continuously pumping.

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The South Perimeter Groundwater Study data is described in the following reports.

- URS. 2002. *South Perimeter Groundwater Study 1<sup>st</sup> Quarter 2002 Field Activities Report*.  
The Dow Chemical Company, Louisiana Operations, Plaquemine, Louisiana.
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## **Appendix B**

### **Geochemical Conceptual Model**

## Appendix B

### Geochemical Conceptual Model

Indicators of the geochemical conditions in the aquifer include dissolved oxygen (DO), nitrate, iron, sulfide, sulfate, methane, hydrogen, and total organic carbon (TOC) concentrations; and the oxidation-reduction potential (ORP). These parameters have been monitored within the remediation study area. Geochemical data from the following sampling events were utilized:

- U. S. Department of Health and Human Services sampling events at Myrtle Grove wells conducted 1994, 1997, 2001;
- LDEQ semi-annual sampling events of wells conducted June 2001 through August 2004;
- Dow sampling events of wells conducted 2001, 2003, 2006;
- Dow (South Perimeter Groundwater Study) sampling events of borings conducted 2001;
- LDEQ sampling event at Myrtle Grove wells conducted 2002; and
- Cooperative Agreement sampling events of wells conducted 2005 to January 2007.

To assess the ambient geochemical conditions based on these data, the average value for each parameter was compared to the published criteria used as indicators of conditions favorable for reductive dechlorination (i.e., show indications of significant anaerobic microbial activity) in the *EPA Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* (EPA 1998) (Table B-1). Calculation of the average value for a parameter included use of data with no analytical quality flags and data with an analytical quality flag of "U" or "J." Data with a "U" flag were considered to have a concentration of zero (non detect). Data with a "J" flag were reported as the instrument data value adjusted for the dilution factor, if any.

Recognizing that these are average values across the remediation study area and that some variation in geochemical conditions exist within the aquifer, the data comparison indicates that the aquifer is generally anoxic with signs of anaerobic activity occurring within or upgradient of the remediation study area (low ORP, low oxygen, presence of reduced iron, methane, hydrogen, and absence of nitrate). The sulfate and sulfide concentrations are not necessarily good indicators of the microbial activity in the aquifer. Low sulfide values in conjunction with low sulfate values are not sufficient to assess the amount of sulfate reduction that may be occurring within or upgradient of the remediation study area because sulfide may be precipitated as an iron sulfide compound not measurable in groundwater samples. The total organic carbon concentration may be sufficient to support continuing anaerobic microbial reactions (e.g., iron reduction, methanogenesis, or reductive dechlorination) though it is lower than the optimal concentration listed in the EPA protocol (EPA 1998). The average pH of the groundwater data is 7.7.

While the above geochemical assessment used a comparison to conditions that are conducive to anaerobic microbial activity and reductive dechlorination, there are other biological mechanisms

for vinyl chloride degradation that can be active under different geochemical conditions. Table B-2 lists the relevant biological reactions and the type of geochemistry supporting these reactions. Geochemical conditions conducive to each of these biological reactions have been observed in some portions of the remediation study area and, therefore, these reactions may be also occurring to some extent in the aquifer.

Histograms showing the concentration/value ranges for the most significant geochemical indicators are shown in Figures B-1 through B-6. In each case, the histogram information and the information in Table B-1 show that the majority of data are consistent with the average geochemical conditions discussed above. Well data with concentrations significantly different than the majority of wells were evaluated graphically to determine if the data were clustered in a manner suggesting large zones of different geochemical conditions. Figures B-7 through B-11 show the distribution of well data with concentrations as indicated in the captions. As observed on the figures, the data values that are significantly different than the majority of other data values are scattered and do not suggest large zones with different geochemical conditions. That is, on the figures, no large area consistently shows red symbols across all of the geochemical indicators, where the red symbol indicates wells where conditions are different than the criteria for anaerobic conditions. These results support the conclusion that while individual wells within the aquifer exist that have conditions differing from the average geochemical conditions, large groups of contiguous wells are not found that have conditions different from the average. Therefore, it is reasonable to base the remediation study on the average geochemical conditions. The geochemical information also suggests that some natural attenuation is occurring within the remediation study area of the aquifer.

## References

EPA. 1998. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water*. EPA/600/R-98, prepared by TH Wiedmeier, MA Swanson, DE Moutoux, EK Gordon, JT Wilson, BH Wilson, DH Kampbell, PE Hass, RN Miller, JE Hansen, and FH Chapelle for the U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

**Table B-1. Comparison of geochemical indicator values in the remediation study area with EPA-established (EPA 1998) indicator values for anaerobic conditions conducive to reductive dechlorination.**

Geochemical Indicator	Criteria for Reductive Dechlorination	Average Value in the Remediation Study Area	Percentage of Wells Meeting Criteria (%)
Oxidation/Reduction Potential (mV)	< -100	-149	88
Hydrogen (nM)	> 1	7.7 <sup>(a)</sup>	90
Methane (mg/L)	> 0.5	2.5	61
Iron (II) (mg/L)	> 1	2.4	55
Dissolved Oxygen (mg/L)	< 0.5	0.75	61
Total Organic Carbon (mg/L)	> 20	3.2	0
Nitrate (mg/L)	< 1	0.03	100
Sulfate (mg/L)	< 20	12.4	68
Sulfide (mg/L)	> 1	0.02	0
(a) Average excludes wells with an average value of greater than 1,000 nM.			

**Table B-2. Potential vinyl chloride degradation reactions.**

Reaction	Geochemistry	Description
Aerobic Co-Metabolism	Dissolved oxygen >0.5 mg/L and presence of co-substrate (e.g., methane)	Dechlorination of a compound where the compound is fortuitously degraded by an enzyme used in cellular metabolism – typically a monooxygenase enzyme.
Aerobic Direct Metabolism	Dissolved oxygen >0.5 mg/L	Use of the chlorinated compound as an electron donor for aerobic metabolism.
Anaerobic Direct Metabolism	Anoxic with appropriate electron acceptors available	Use of the chlorinated compound as an electron donor for anaerobic respiration – typically coupled to iron reduction.
Reductive Dechlorination (hydrogenolysis)	Anoxic, typical conditions listed in Table B-1	Dechlorination of a compound where the compound is used as an electron acceptor. The bacteria may or may not gain energy by reduction of the compound. This reaction removes one chloride atom from the compound and replaces it with a proton.

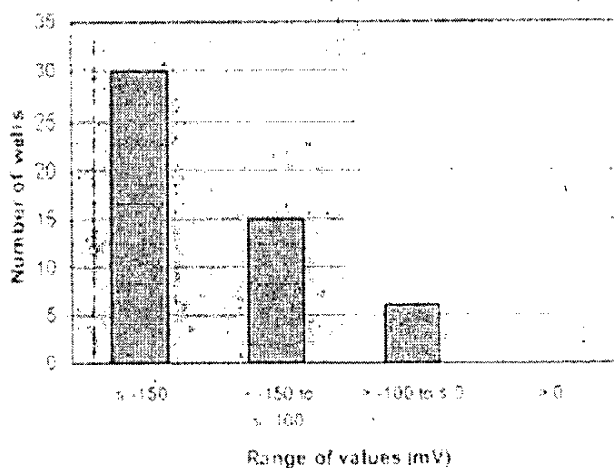


Figure B-1 Distribution of oxidation-reduction potential measurements. Shaded area indicates the conditions reported by EPA to be favorable for reductive dechlorination.

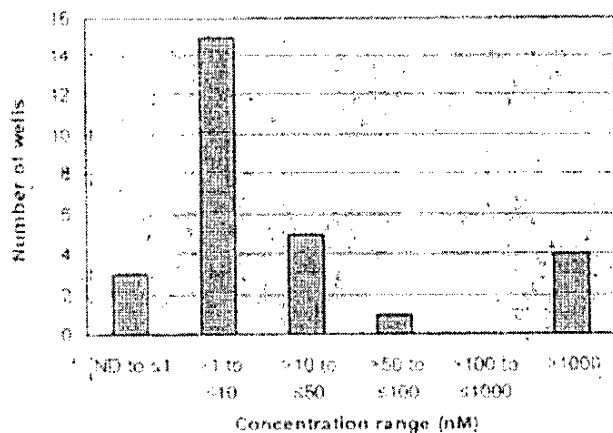


Figure B-2 Distribution of hydrogen concentrations. Shaded area indicates the conditions reported by EPA to be favorable for reductive dechlorination.

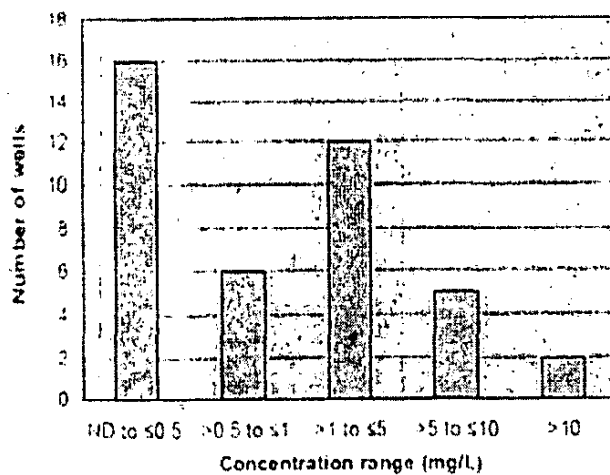


Figure B-3 Distribution of methane concentrations. Shaded area indicates the conditions reported by EPA to be favorable for reductive dechlorination.

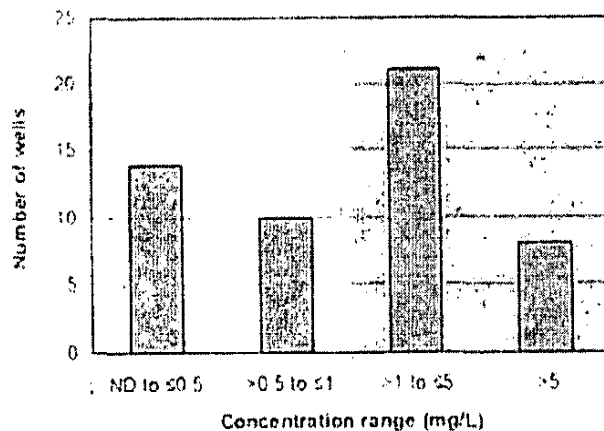


Figure B-4 Distribution of iron (II) concentrations. Shaded area indicates the conditions reported by EPA to be favorable for reductive dechlorination. Note that iron reduction can also support anaerobic oxidation of DCE and vinyl chloride.

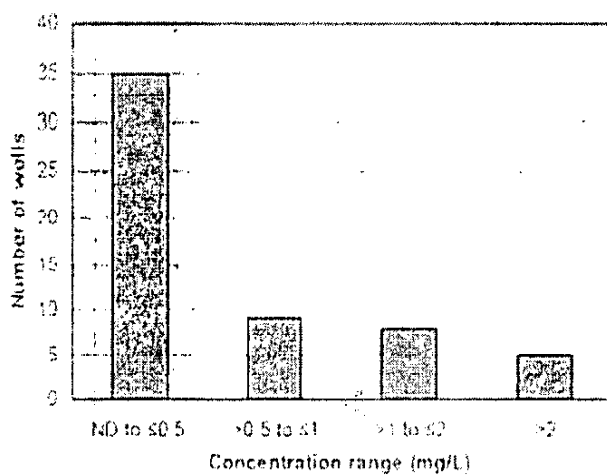


Figure B-5 Distribution of dissolved oxygen concentrations. Shaded area indicates the conditions reported by EPA to be favorable for reductive dechlorination. Note that aerobic conditions (oxygen concentrations greater than 0.5 mg/L) can also support aerobic vinyl chloride biodegradation.

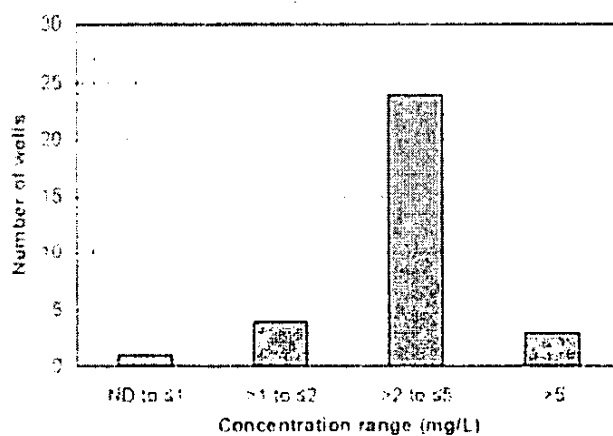


Figure B-6 Distribution of total organic carbon concentrations. Total organic carbon concentrations in all wells were below the EPA indicator criteria for optimal reductive dechlorination.





Figure B-7 Variation in oxidation-reduction potential where the yellow well symbol indicates wells where conditions meet the criteria suitable for reductive dechlorination (EPA 1998). The blue well symbol corresponds to wells where conditions do not meet the criteria for reductive dechlorination (EPA 1998).

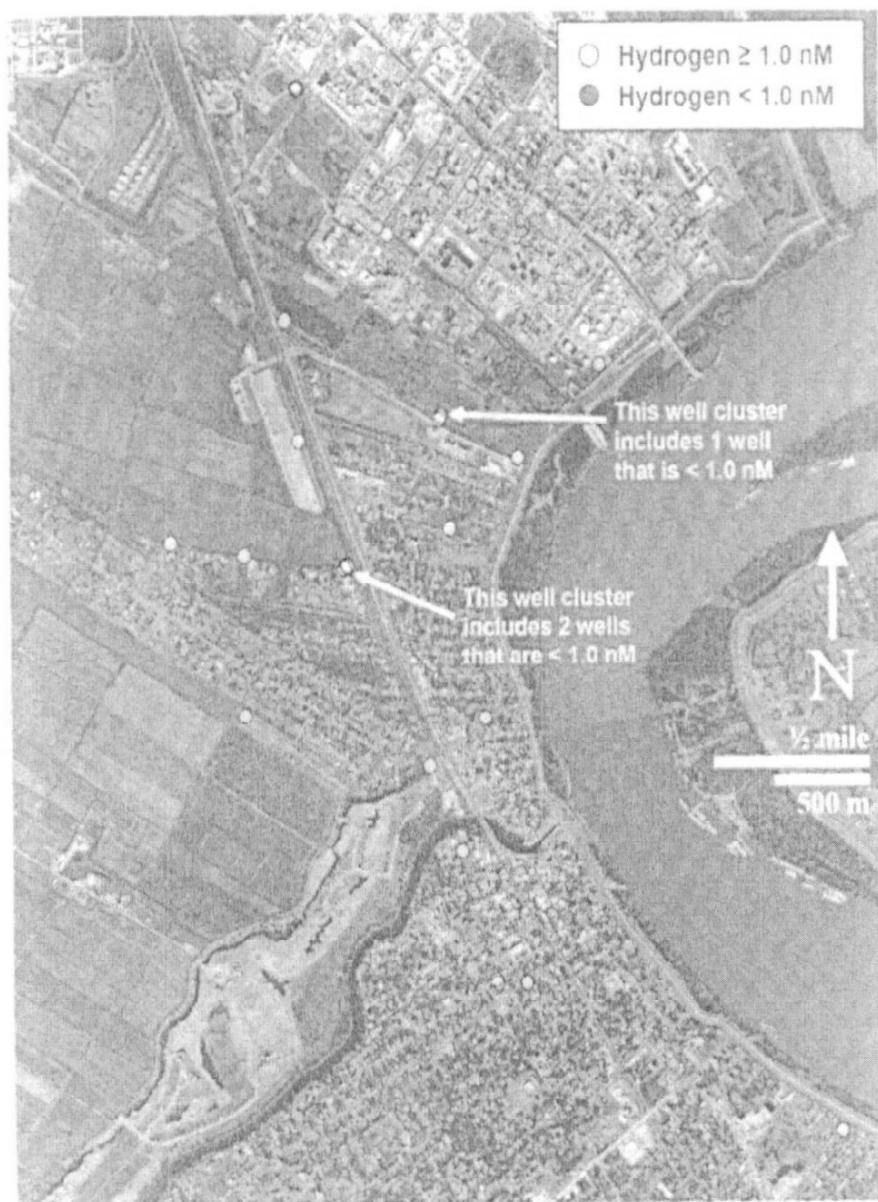


Figure B-8 Variation in hydrogen concentrations where the yellow well symbol indicates wells where conditions meet the criteria suitable for reductive dechlorination (EPA 1998). The blue well symbol corresponds to wells where conditions do not meet the criteria for reductive dechlorination (EPA 1998).

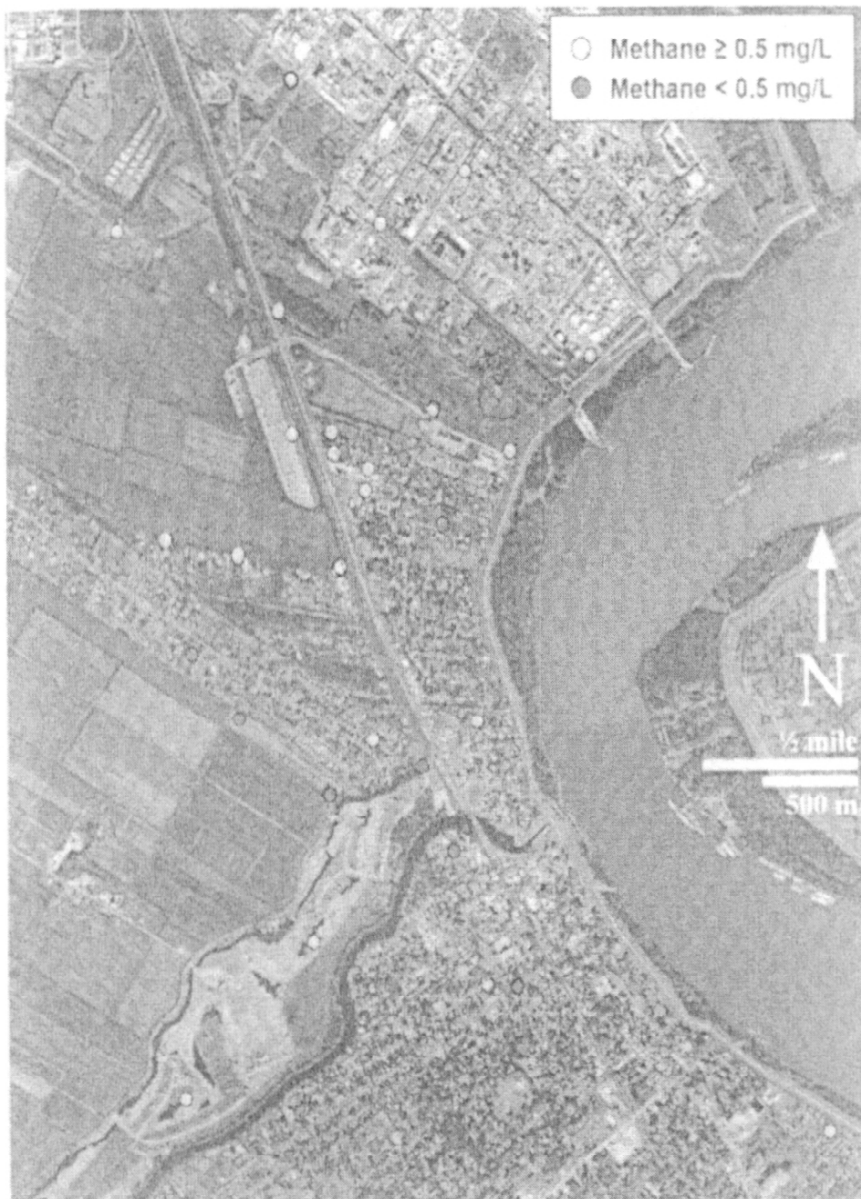


Figure B-9. Variation in methane concentrations where the yellow well symbol indicates wells where conditions meet the criteria suitable for reductive dechlorination (EPA 1998). The blue well symbol corresponds to wells where conditions do not meet the criteria for reductive dechlorination (EPA 1998).

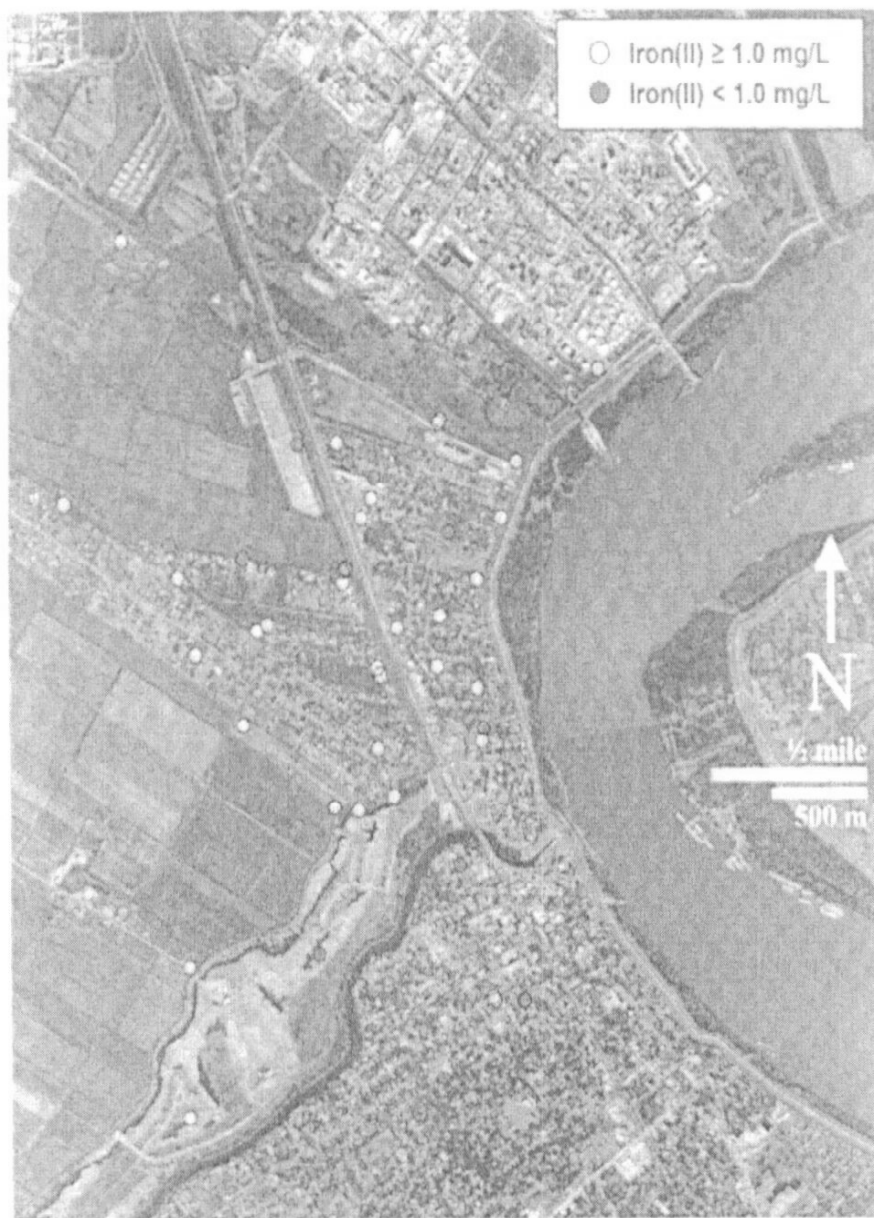


Figure B-10 Variation in iron (II) concentrations where the yellow well symbol indicates wells where conditions meet the criteria suitable for reductive dechlorination (EPA 1998). The blue well symbol corresponds to wells where conditions do not meet the criteria for reductive dechlorination (EPA 1998). Note that iron reduction can also support anaerobic oxidation of DCE and vinyl chloride.

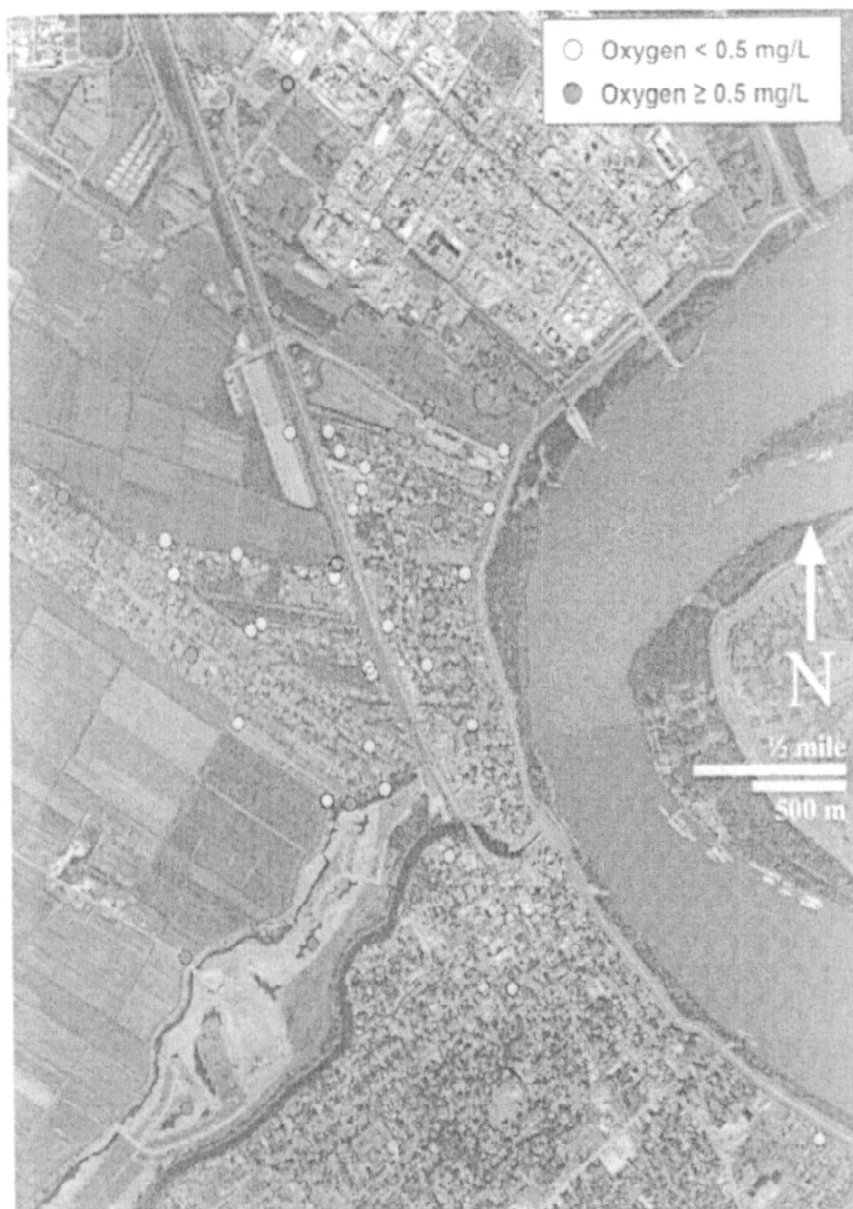


Figure B-11. Variation in dissolved oxygen concentrations where the yellow well symbol indicates wells where conditions meet the criteria suitable for reductive dechlorination (EPA 1998). The blue well symbol corresponds to wells where conditions do not meet the criteria for reductive dechlorination (EPA 1998). Note that aerobic conditions (oxygen concentrations greater than 0.5 mg/L) can also support aerobic VC biodegradation.

## **Appendix C**

### **Potential Remediation Methods**

## **Appendix C**

### **Potential Remediation Methods**

This appendix lists remediation methods potentially applicable to this remediation study. These remediation methods were identified based on a review of technical literature and environmental technology databases (e.g., U. S. Environmental Protection Agency resources) for methods that have been used or tested to remediate vinyl chloride at other sites. This listing provided the starting point for development and evaluation of remedial alternatives for application to the Plaquemine Aquifer.

Table C-1. Technologies for vinyl chloride treatment.

Technology	Contaminant	Maturity	Reference
<b>Bioremediation - General</b>			
Laboratory Microbiology Study	VC, others	Laboratory / Lab Scale	Cupples, A., A. Spormann, and P. McCarty. 2003. "Growth of a Dehalococcoides-like Microorganism on Vinyl Chloride and cis-Dichloroethene as Electron Acceptors as Determined by Comparative PCR." <i>Appl. Environ. Microbiol.</i> , 69(2):953-959.
Laboratory Microbiology Study	VC, others	Laboratory / Lab Scale	Freedman, D., and S. Herz. 1996. "Use of Ethylene and Ethane as Primary Substrates for Aerobic Comestabolism of Vinyl Chloride." <i>Water Environ. Res.</i> , 68(3):320-328.
Laboratory Microbiology Study	VC, others	Laboratory / Lab Scale	Jianzong, H., K. Rihalahti, M. Alejo, and F. Löffler. 2003. "Complete Detoxification of Vinyl Chloride by an Anaerobic Enrichment Culture and Identification of the Reductively Dechlorinating Population as a <i>Dehalococcoides</i> Species." <i>Appl. Environ. Microbiol.</i> , 69(2):996-1003.
<b>Monitored Natural Attenuation</b>			
Monitored Natural Attenuation	Vinyl Chloride	Mature	EPA/600/R-98/128. <i>Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents</i>
<b>Ex Situ Treatment</b>			
Extraction - Dual Phase Extraction	Vinyl Chloride	Commercial / Field Scale	Federal Remediation Technologies Roundtable, Remediation Technologies Screening Matrix and Reference Guide, 4th Edition http://www.ftr.gov/matrix2/section4/4-37.html http://www.ftr.gov/matrix2/section4/4-41.html http://www.gpo.org/techtree/tidscript/qualipha.htm http://www.deln.org/vendor/vendorinfo/ http://cdi-in.org/download/remed/mpc2.pdf http://cdi-in.org/techtools/default.focus/sec/Nutrd%20Phase%20Extraction/cat/Overview/ EPA 540/R-96/023, <i>Presumptive Response Strategy and Ex-situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites</i> , pg. 21
Air Stripping	Vinyl Chloride	Presumptive	EPA 540/R-96/023 http://www.grusa.com/env_svcs_01_5.htm
Biological Treatment - Aerobic biological reactors	Vinyl Chloride	Presumptive	EPA 540/R-96/023
Chemical Treatment - Granular Activated Carbon	Vinyl Chloride	Presumptive	EPA 540/R-96/023
Chemical Treatment - Catalytic dechlorination	Vinyl Chloride	Commercial	EPA 540/R-96/023, Appendix C1, p C-2
Chemical Treatment - Catalytic dehydrochlorination	Vinyl Chloride	Commercial	EPA 540/R-96/023, Appendix C1, pg. C-2
Chemical Treatment - Chemical / UV Oxidation	Vinyl Chloride	Presumptive	EPA 540/R-96/023
Chemical Treatment - Electrochemical Remediation	VC, others	Innovative / Pilot Scale	Baun, D., L. Andersen, and C. Nielsen. 2004. "Electrochemical Remediation of Groundwater Contaminated with Chlorinated Compounds." Proceedings of the Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Battelle Press, Columbus, Ohio. Paper 3C-12.



Table C-1. Technologies for vinyl chloride treatment. (contd.)

Technology	Contaminant	Maturity	Reference
<b>Ex Situ Treatment (contd.)</b>			
Chemical Treatment - Liquid-Liquid Extraction	Vinyl Chloride	Commercial	EPA 540/R-96/023, Appendix C1, pg. C-2
Thermal Treatment - High Temperature Separation	Vinyl Chloride	Commercial	EPA 540/R-96/023, Appendix C1, pg. C-2
Thermal Treatment - Thermal Destruction	Vinyl Chloride	Commercial	EPA 540/R-96/023, Appendix C1, pg. C-2
Physical Treatment - Evaporation Basin	Vinyl Chloride	Mature	EPA 540/R-96/023, Appendix C1, pg. C-2
Physical Treatment - Membrane Filtration	Vinyl Chloride	Commercial	EPA 540/R-96/023, Appendix C1, pg. C-2
<b>In Situ Treatment - Chemical Oxidation</b>			
Fenton's reagent	Vinyl Chloride	Innovative	<a href="http://www.cpeo.org/techtree/ttdescript/iscop.htm">http://www.cpeo.org/techtree/ttdescript/iscop.htm</a> <a href="http://ctu-in.org/techfocus/default.focus/sec/in%5FSitu%5FOxidation/cal/Overview/">http://ctu-in.org/techfocus/default.focus/sec/in%5FSitu%5FOxidation/cal/Overview/</a> <a href="http://www.ftr.gov/matrix2/section4/4-30.html">http://www.ftr.gov/matrix2/section4/4-30.html</a> In-Situ Oxidative Technologies, Inc. <a href="http://www.insituoxidation.com/pages/833736/index.htm">http://www.insituoxidation.com/pages/833736/index.htm</a> Characterization Technology Vendor Summary <a href="http://www.cduin.org/vendor/vendorinfo/">http://www.cduin.org/vendor/vendorinfo/</a> Prasad K. Kalanta, Thomas Andrews, Richard S. Greenberg, David S. Zervas. 2002. "Modified Fenton's processes for effective in-situ chemical oxidation - Laboratory and field evaluation." <i>Remediation J.</i> , 12(4):23-36.
BIOX®	Vinyl Chloride	Innovative	EPA Characterization Technology Vendor Summary <a href="http://www.cduin.org/vendor/vendorinfo/">http://www.cduin.org/vendor/vendorinfo/</a> BMS, Inc. ( <a href="http://www.bioxtech.com/bioxprocess.html">http://www.bioxtech.com/bioxprocess.html</a> ) <a href="http://www.dep.state.nj.us/waste/quick_topics/publications/pss/pcp/innovative/letters/in_n_123.pdf">http://www.dep.state.nj.us/waste/quick_topics/publications/pss/pcp/innovative/letters/in_n_123.pdf</a>
Geo-Cleanse®	Vinyl Chloride	Innovative	EPA Characterization Technology Vendor Summary <a href="http://www.cduin.org/vendor/vendorinfo/">http://www.cduin.org/vendor/vendorinfo/</a> Geo-Cleanse International, Inc. ( <a href="http://www.geocleanse.com/">http://www.geocleanse.com/</a> ) <a href="http://www.contaminment.fsu.edu/od/content/pd/211.pdf">http://www.contaminment.fsu.edu/od/content/pd/211.pdf</a> <a href="http://www.p2pays.org/ref/14/10_initiatives/init/spring98/geo.htm">http://www.p2pays.org/ref/14/10_initiatives/init/spring98/geo.htm</a> <a href="http://www.geocleanse.com/pdf/SavannahSiteSummary.pdf">http://www.geocleanse.com/pdf/SavannahSiteSummary.pdf</a>
<b>In Situ Treatment - Zero-Valent Iron</b>			
Nanoscale Fe-Modified Fe Particles	VC, others	Innovative / Lab Tests/Field Test	Zhang, W. 2003. "Nanoscale Iron particles for Environmental Remediation: An Overview." <i>J. Nanopart. Res.</i> , 5(3-4):323-332.
In-situ Chemical Treatment - Z-Loy™	Vinyl Chloride	Innovative	<a href="http://www.cdu-in.org/download/remed/or-05-007-env.pdf">http://www.cdu-in.org/download/remed/or-05-007-env.pdf</a> OnMaterials ( <a href="http://www.z-loy.com/index.jsp?id=587&amp;expand=48.3">http://www.z-loy.com/index.jsp?id=587&amp;expand=48.3</a> )

Table C-1. Technologies for vinyl chloride treatment. (contd.)

Technology	Contaminant	Maturity	Reference
<b>In Situ Treatment - Air Sparging</b>			
In-situ Air Sparging	Vinyl Chloride	Innovative	<a href="http://www.epa.gov/OUST/cat/airsparg.htm">http://www.epa.gov/OUST/cat/airsparg.htm</a> <a href="http://www.frt.gov/matrix2/section4/4-34.html">http://www.frt.gov/matrix2/section4/4-34.html</a> <a href="http://www.usace.army.mil/publications/eng-manuals/em1110-1-4005/tox.htm">http://www.usace.army.mil/publications/eng-manuals/em1110-1-4005/tox.htm</a> <a href="http://www.culn.org/download/toolkit/sparge_o.pdf">http://www.culn.org/download/toolkit/sparge_o.pdf</a> <a href="http://clu-in.org/techfocus/default.focus?sec=Air%2FSparging/cat/Overview/">http://clu-in.org/techfocus/default.focus?sec=Air%2FSparging/cat/Overview/</a>
In-situ Air Sparging with In-situ Soil Vapor Extraction	Vinyl Chloride	Innovative	EPA-542-R-97-007, <i>Analysis of Selected Enhancements for Soil Vapor Extraction</i> , <a href="http://www.culn.org/download/remed/s_vtechnrti.pdf">http://www.culn.org/download/remed/s_vtechnrti.pdf</a> <a href="http://www.p2pays.org/ref/07/06192/">http://www.p2pays.org/ref/07/06192/</a> <a href="http://www.frt.gov/matrix2/section4/4_9.htm">http://www.frt.gov/matrix2/section4/4_9.htm</a> <a href="http://www.deltamag.com/issues/2002/april_may/soil_vapor.htm">http://www.deltamag.com/issues/2002/april_may/soil_vapor.htm</a>
<b>In Situ Treatment - In-well Air Stripping</b>			
In-well Air Stripping	Vinyl Chloride	Innovative	<a href="http://www.frt.gov/matrix2/section4/4-40.htm">http://www.frt.gov/matrix2/section4/4-40.htm</a> <a href="http://www.cped.org/techtree/todescript/inwellvp.htm">http://www.cped.org/techtree/todescript/inwellvp.htm</a> <a href="http://www.culn.org/download/remed/inwellvp.pdf">http://www.culn.org/download/remed/inwellvp.pdf</a> <a href="http://www.engg.ksu.edu/QHSR/outreach/tosc/sites/60cs/57th_vapor.pdf">http://www.engg.ksu.edu/QHSR/outreach/tosc/sites/60cs/57th_vapor.pdf</a> <a href="http://apps.em.doe.gov/ost/pubs/ltr6.pdf">http://apps.em.doe.gov/ost/pubs/ltr6.pdf</a> <a href="http://www.osl.gov/bridge/services/pur/7520-QCskm4/webviewable/7520.pdf">http://www.osl.gov/bridge/services/pur/7520-QCskm4/webviewable/7520.pdf</a> <a href="http://clu-in.org/products/siteprof/2004/trackrockant/cdr_pdfs/indexed/group1/059.pdf">http://clu-in.org/products/siteprof/2004/trackrockant/cdr_pdfs/indexed/group1/059.pdf</a>
UVB Technology	Vinyl Chloride	Innovative	<a href="http://www.epa.gov/ORD/SITE/reports/540r95500/540r95500.htm">http://www.epa.gov/ORD/SITE/reports/540r95500/540r95500.htm</a> <a href="http://www.frt.gov/matrix2/section4/4-40.htm">http://www.frt.gov/matrix2/section4/4-40.htm</a> <a href="http://apps.em.doe.gov/ost/pubs/ltr6.pdf">http://apps.em.doe.gov/ost/pubs/ltr6.pdf</a>
Density Driven Convection	Vinyl Chloride	Innovative	<a href="http://www.culn.org/download/remed/inwellvp.pdf">http://www.culn.org/download/remed/inwellvp.pdf</a> <a href="http://clu-in.org/download/remed/gwdrnc.pdf">http://clu-in.org/download/remed/gwdrnc.pdf</a> Wesatch Environmental, <a href="http://www.wesatch-environmental.com/ddc.htm">http://www.wesatch-environmental.com/ddc.htm</a> Advanced Groundwater Remediation, <a href="http://www.sterewilhelm.net/gdc.htm">http://www.sterewilhelm.net/gdc.htm</a> <a href="http://www.adventu-group.com/pdfs/Superfund97_GCW_paper.pdf">http://www.adventu-group.com/pdfs/Superfund97_GCW_paper.pdf</a>
<b>In Situ Treatment - Phytoremediation</b>			
Phytoremediation	VCl, TCE, others	Innovative / Field Scale	Sorrigs, T., S. Tsangaris, R. Tossell, and B. Nwokike. 2004. "Phytoremediation of a Chlorinated Solvent Plume Using Fast-Growing Native and Hybrid Poplar Trees." Proceedings of the Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Battelle Press, Columbus, Ohio. Paper 4E-OS.

Table C-1. Technologies for vinyl chloride treatment. (contd.)

Technology	Contaminant	Maturity	Reference
<b>In Situ Treatment</b>			
Biosparging	Vinyl Chloride	Innovative	<a href="http://www.epa.gov/OUST/cat/biosparg.htm">http://www.epa.gov/OUST/cat/biosparg.htm</a> <a href="http://www.epa.gov/OUST/pubs/tum_ch8.pdf">http://www.epa.gov/OUST/pubs/tum_ch8.pdf</a> <a href="http://www.culn.org/download/toolkit/sparge_o.pdf">http://www.culn.org/download/toolkit/sparge_o.pdf</a> <a href="http://www.envirotools.org/factsheets/Remediation/Biosparging.pdf">http://www.envirotools.org/factsheets/Remediation/Biosparging.pdf</a> <a href="http://culn.org/techfocus/default.focus/sec/Bioventing%252FBiosparging/cat/Overview/">http://culn.org/techfocus/default.focus/sec/Bioventing%252FBiosparging/cat/Overview/</a> Sperry et al. 2001. "Field Trial of Biosparging with Oxygen for Bioremediation of Volatile Organic Compounds." <i>Remediation J.</i> , 11(4):47-62.
Biosparging - Butane substrate	Vinyl Chloride	Innovative	<a href="http://www.globalbiociences.com/downloads/Butane_Reme.pdf">http://www.globalbiociences.com/downloads/Butane_Reme.pdf</a> Global Bio Sciences, <a href="http://www.globalbiociences.com/products/groundwater.php">http://www.globalbiociences.com/products/groundwater.php</a>
Biosparging - ORC	Vinyl Chloride	Innovative	<a href="http://culn.org/download/remed/engappinsitbio.pdf">http://culn.org/download/remed/engappinsitbio.pdf</a> <a href="http://www.regenesis.com/products/enh/aer/orc/publications/aerobic_anaerobic.aspx">http://www.regenesis.com/products/enh/aer/orc/publications/aerobic_anaerobic.aspx</a>
Biosparging - Ozone	Vinyl Chloride	Innovative	<a href="http://www.itrcweb.org/Documents/ISCO-2.pdf">http://www.itrcweb.org/Documents/ISCO-2.pdf</a> <a href="http://www.culn.org/download/toolkit/sparge_o.pdf">http://www.culn.org/download/toolkit/sparge_o.pdf</a> H2O Engineering, <a href="http://www.h2oengineering.com/about_ozone_sparge.html">http://www.h2oengineering.com/about_ozone_sparge.html</a>
Aerobic Biodegradation	VC, others	Innovative / Field Trial	Begeley, J., and C. LeBlenc. 2004. "Comparison of Oxygen Delivery Methods for In Situ Vinyl Chloride Treatment." Proceedings of the Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Battelle Press, Columbus, Ohio. Paper 3D-14.
Aerobic Biodegradation	VC, others	Innovative / Pilot Test	Harwood, C., and R. Bonelli. 2004. "Oxygen-Based Vinyl Chloride Remediation." Proceedings of the Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Battelle Press, Columbus, Ohio. Paper 3D-13.
Aerobic Biodegradation	VC, others	Innovative / Pilot Test/Field Scale Follow-on	Johnson, C.D., M.J. Truex, D.P. Leigh, and S. Granade. 2003. "Successful Implementation of Aerobic Comatabolism of Vinyl Chloride Via an In Situ Biofilter." In: Proceedings of the Seventh In Situ and On-Site Bioremediation Symposium, Orlando, Florida; June 2-5, 2003. Battelle Press, Columbus, Ohio. Paper A-43.
Aerobic & Anaerobic Biodegradation	VC, others	Innovative / Field Scale	Williams, O., E. Eveland, G. Branham, D. Boyle, L. White, J. Carrig, M. Anderson, J. Haseloff, and K. Domako. 2004. "Comparative Evaluation of Enhanced Anaerobic and Aerobic Bioremediation." Proceedings of the Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Battelle Press, Columbus, Ohio. Paper 3D-15.

Table C-1. Technologies for vinyl chloride treatment. (contd.)

Technology	Contaminant	Maturity	Reference
<b>In Situ Treatment - Anaerobic Bioremediation</b>			
In-situ Enhanced Bioremediation	Vinyl Chloride	Innovative	<a href="http://www.ftr.gov/matrix2/section4/4_31.html">http://www.ftr.gov/matrix2/section4/4_31.html</a> <a href="http://www.ftr.gov/matrix2/section4/4_34.html">http://www.ftr.gov/matrix2/section4/4_34.html</a> <a href="http://cluin.org/techfocus/default_focus/sec/Bioremediation%5Fof%5FChlorinated%5FSolvents/cat/Overview/">http://cluin.org/techfocus/default_focus/sec/Bioremediation%5Fof%5FChlorinated%5FSolvents/cat/Overview/</a> <a href="http://www.libweb.org/Documents/ISB-8.pdf">http://www.libweb.org/Documents/ISB-8.pdf</a> <a href="http://enviro.nfesc.navy.mil/scripts/WebObjects.exe/erweb.woa/6/wa/DisplayPage?pag eShortName=Bioremediation&amp;PageID=64">http://enviro.nfesc.navy.mil/scripts/WebObjects.exe/erweb.woa/6/wa/DisplayPage?pag eShortName=Bioremediation&amp;PageID=64</a> <a href="http://www.atcee.brooks.af.mil/products/techtrans/bioremediation/downloads/principles andPractices.pdf">http://www.atcee.brooks.af.mil/products/techtrans/bioremediation/downloads/principles andPractices.pdf</a> (or <a href="http://www.siremlab.com/pdf/AFCOE-Aerobic-Bio-Principles-and-Practices.pdf">http://www.siremlab.com/pdf/AFCOE-Aerobic-Bio-Principles-and-Practices.pdf</a> ) <a href="http://www.epa.gov/ORD/NRMML/pubs/540r00504/540r00504.pdf">http://www.epa.gov/ORD/NRMML/pubs/540r00504/540r00504.pdf</a> <i>EPA 542-R-00-008, Engineered Approaches to In Situ Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications</i> <a href="http://www.adventusgroup.com/pdfs/EHCtechsumm.pdf">http://www.adventusgroup.com/pdfs/EHCtechsumm.pdf</a> <a href="http://www.adventus.us/ehc.htm">http://www.adventus.us/ehc.htm</a> <a href="http://www.adventusgroup.com/chenrypt_ehc.shtml">http://www.adventusgroup.com/chenrypt_ehc.shtml</a>
Reductive Dechlorination / EHC	Vinyl Chloride	Innovative	<a href="http://www.adventusgroup.com/pdfs/EHCtechsumm.pdf">http://www.adventusgroup.com/pdfs/EHCtechsumm.pdf</a> <a href="http://www.adventus.us/ehc.htm">http://www.adventus.us/ehc.htm</a> <a href="http://www.adventusgroup.com/chenrypt_ehc.shtml">http://www.adventusgroup.com/chenrypt_ehc.shtml</a>
<b>In Situ Treatment - Thermal Treatment</b>			
Steam Heating	Vinyl Chloride	Innovative	<a href="http://www.du-in.org/PRODUCTS/SITE/ongoing/demonog/praxis.htm">http://www.du-in.org/PRODUCTS/SITE/ongoing/demonog/praxis.htm</a> <a href="http://www.kubed.com/gwrtac/html/thermal.html">http://www.kubed.com/gwrtac/html/thermal.html</a>
Electrical Heating - Six Phase	Vinyl Chloride	Innovative	<a href="http://www.cpeo.org/techtree/ttdscript/sstsoil.htm">http://www.cpeo.org/techtree/ttdscript/sstsoil.htm</a> <a href="http://www.asl.gov/bridge/services/purl/10193982-SN106s/webviewable/10193982.pdf">http://www.asl.gov/bridge/services/purl/10193982-SN106s/webviewable/10193982.pdf</a> <a href="http://www.thermaltr.com/TRS_docs/ThreePhase_vs_SixPhase.pdf">http://www.thermaltr.com/TRS_docs/ThreePhase_vs_SixPhase.pdf</a> Smart, J.L. 2004. "Application of six-phase soil heating technology for groundwater remediation." <i>Environmental Progress</i> , 24(1):34-43. <a href="https://www.oconor-associates.com/papers/2000-Ground-Heating.pdf">https://www.oconor-associates.com/papers/2000-Ground-Heating.pdf</a> CES. <a href="http://www.cesiweb.com/powerool.htm">http://www.cesiweb.com/powerool.htm</a> <a href="http://costperformance.org/profile.cfm?ID=296&amp;CaseID=296">http://costperformance.org/profile.cfm?ID=296&amp;CaseID=296</a>
Electrical Heating - ET-DSP	Vinyl Chloride	Innovative	<a href="http://www.terrafirm.com/resources/TechPapers/Heat%20it%20all%20the%20way-2006.pdf">http://www.terrafirm.com/resources/TechPapers/Heat%20it%20all%20the%20way-2006.pdf</a> <a href="http://www.im.doe.gov/documents/3_pro_doc/8_references/papers/dnapt_heron05_04.pdf">http://www.im.doe.gov/documents/3_pro_doc/8_references/papers/dnapt_heron05_04.pdf</a> McMillan-McGee Corporation, <a href="http://www.mcmillan-mcgee.com/index.php">http://www.mcmillan-mcgee.com/index.php</a>

Table C-1. Technologies for vinyl chloride treatment. (contd.)

Technology (In-Situ Treatment)	Contaminant (Permeable Reactive Barrier)	Maturity	Reference
Zero-Valent Iron	Vinyl Chloride	Innovative	<a href="http://www.ftr.gov/matrix2/section4/4-41.html">http://www.ftr.gov/matrix2/section4/4-41.html</a> <a href="http://china.org/techfocus/default_focus/sec/Permeable%5FReactives%5FBarriers/cat/Oveview/">http://china.org/techfocus/default_focus/sec/Permeable%5FReactives%5FBarriers/cat/Oveview/</a> <a href="http://www.cpa.org/techtree/tdescript/permbarr.htm">http://www.cpa.org/techtree/tdescript/permbarr.htm</a> <a href="http://es.epa.gov/nce/pubs/publications/workshop/pdf/10_20_05_quinn_jacqueline.pdf">http://es.epa.gov/nce/pubs/publications/workshop/pdf/10_20_05_quinn_jacqueline.pdf</a> <a href="http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15573.pdf">http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15573.pdf</a> <a href="http://enviro.nhsc.navy.mil/scripts/WebObjects.exe/erbweb.woa/6/wa/DisplayPage?pag&amp;ShortName=NZVIB&amp;PageID=416">http://enviro.nhsc.navy.mil/scripts/WebObjects.exe/erbweb.woa/6/wa/DisplayPage?pag&amp;ShortName=NZVIB&amp;PageID=416</a> <a href="http://www.lehigh.edu/nano/WetZhang2.pdf">http://www.lehigh.edu/nano/WetZhang2.pdf</a> <a href="http://www.geoslerma.com/deep_prb.html">http://www.geoslerma.com/deep_prb.html</a>
Zero-Valent Iron - FEROX	Vinyl Chloride	Innovative	<a href="http://enviro.nhsc.navy.mil/erb/erb_a/support/wrk_grip/arc/zv-ir-pres.pdf">http://enviro.nhsc.navy.mil/erb/erb_a/support/wrk_grip/arc/zv-ir-pres.pdf</a> ARS Technologies, Inc., <a href="http://www.ars technologies.com/ferox_zero_valent_iron.html">http://www.ars technologies.com/ferox_zero_valent_iron.html</a>
Zero-Valent Iron & Carbon	VC, others	Innovative / Batch/Column Tests/Field- Scale Design Study	Gibson, M., D. Kill, J. Mueller, and A. Seech. 2004. "Placement of EHC™ by Hydrofracturing to Treat Chlorinated Solvent Plumes." Proceedings of the Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Battelle Press, Columbus, Ohio. Paper 3A-26.
Zero-Valent Iron & Carbon	VC, PCE, TCE, Cr, others	Laboratory / Lab Scale	Oberle, D., and D. Schroder. 2004. "Absorptive/Reductive Contaminant Treatment in Laboratory Using Iron-Impregnated sand." Proceedings of the Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Battelle Press, Columbus, Ohio. Paper 3A-18.
In-situ Bimetallic Nanoscale Iron	Vinyl Chloride	Innovative	<a href="http://www.ltrweb.org/Documents/sedimentsglisides.pdf">http://www.ltrweb.org/Documents/sedimentsglisides.pdf</a> <a href="http://www.rtdf.org/public/permbarr/minutes/110702/zhang.pdf">http://www.rtdf.org/public/permbarr/minutes/110702/zhang.pdf</a> <a href="http://www.du-in.org/PRODUCTS/NEWSLTRS/tnandt/view.cfm?issue=0304.cfm">http://www.du-in.org/PRODUCTS/NEWSLTRS/tnandt/view.cfm?issue=0304.cfm</a>
In-situ Aerobic, Permeable Reactive Zone	Vinyl Chloride	Innovative	<a href="http://www.ltrweb.org/documents/prb-4.pdf">http://www.ltrweb.org/documents/prb-4.pdf</a>

## **Appendix D**

### **Remediation Parameter Estimates For Scoping Calculations**

## Appendix D

### Remediation Parameter Estimates For Scoping Calculations

Remediation methods must address the contamination in the setting defined by the conceptual model (Section 2.1). Using the conceptual model framework, the scale of key remediation-related parameters can be calculated and used to assess whether a potential method can effectively function within this context. General scale parameters are presented here for use in the evaluation process described in Section 4 of the report and in Appendix G.

The physical size of the treatment volume can be quantified in terms of how methods would be applied where water wells are required as part of the application. For a single water well, volumes and groundwater travel time as a function of radial distances are important to consider for evaluating remediation operations. Table D-1 shows the aquifer volumes and groundwater volume as a function of radial distance from a well and the time required to either inject or extract the groundwater volume as a function of well flow rate.

The oxygen demand of the groundwater and aquifer solids can be an important factor in considering technologies that rely on oxidizing processes. When reagent is injected in situ, oxidant can be consumed by the oxygen demand in the groundwater and aquifer in addition to the desired reagent use for oxidation of the contaminant. Ex situ treatment or systems using groundwater recirculation must also consider oxidation of constituents, such as iron that may precipitate and cause fouling of equipment unless the iron precipitate is properly considered in the design. Table D-2 shows the primary oxidizable constituents of the groundwater and their oxygen demand expressed in units of mmol/L of molecular oxygen required for complete oxidation of the constituent. Table D-3 lists the oxygen demand of the aquifer solids as a function of radial distance from a well based on the organic carbon content as the primary oxygen demand for strong oxidants that may be injected as part of an in situ remediation technology.

#### References

Sposito G. 1989. *The Chemistry of Soils*. Oxford University Press, New York.

PTS Laboratories, Inc. 2006. *Geotechnical Analysis*. PTS File 35110, PTS Laboratories, Inc., Santa Fe Springs, California.

Table D-1. Volumes and groundwater travel times as a function of radius from a well.

Radius (ft)	Aquifer Volume (ft <sup>3</sup> )	Groundwater Volume <sup>(a)</sup> (gal.)	Time to Inject/Extract Groundwater Volume (days)		
			Well Flow Rate: 1,000 gpm	Well Flow Rate: 2,000 gpm	Well Flow Rate: 3,000 gpm
100	4.71E6	1.06E7	7.34	3.67	2.45
200	1.88E7	4.23E7	29.4	16.7	9.79
300	4.24E7	9.52E7	66.1	33.0	22.0
400	7.54E7	1.69E8	117	58.7	39.2
500	1.18E8	2.64E8	184	91.8	61.2
Total treatment volume	7.0E9	1.58E10	NA <sup>(b)</sup>	NA	NA
(a) Computed using aquifer properties listed in Table A-1 (Appendix A).					
(b) NA = Not applicable.					

Table D-2. Primary oxidizable materials in the groundwater.

Compound	Concentration (mg/L)	Molecular weight (mg/mmol)	Concentration (mM)	Oxygen stoichiometry	Oxygen demand <sup>(a)</sup> (mmol/L)
Total Organic Carbon	3.2	88 <sup>(b)</sup>	0.036	5 <sup>(b)</sup>	0.18
Iron(II)	2.4	56	0.043	0.25	0.01
Methane	2.7	16	0.17	2	0.34
Total					0.53
(a) Dissolved oxygen at 10 mg/L is equivalent to 0.3125 mmol/L of oxygen.					
(b) Based on using butyrate to represent the nature of the dissolved organic carbon.					



Table D-3. Oxygen demand of aquifer solids for the measured average value of the fraction of organic carbon ( $f_{oc}$ ) (PTS 2006).

Radius (ft)	Volume of Aquifer (ft <sup>3</sup> )	Mass of Aquifer Solids (kg)	$f_{oc} = 0.0019$ Mass of Organic Carbon (kg)	$f_{oc} = 0.0019$ Oxygen Demand <sup>(a)</sup> (mol)
100	4.71E6	2.40E8	4.6E5	2.2E7
200	1.88E7	9.61E8	1.8E6	8.6E7
300	4.24E7	2.16E9	4.1E6	1.9E8
400	7.54E7	3.84E9	7.3E6	3.4E8
500	1.18E8	6.00E9	1.1E7	5.4E8
Total treatment volume	7.0E9	3.60E11	6.7E8	3.2E10
(a) Calculations based on complete oxidation of organic carbon. The composition of the organic carbon was taken as the average composition (molecular formula) of humic acid reported in Sposito (1989).				

## **Appendix E**

### **Site-Specific Approach to Meet the Objectives of the EPA Monitored Natural Attenuation Directive**

## Appendix E

### Site-Specific Approach to Meet the Objectives of the EPA Monitored Natural Attenuation Directive

The U. S. Environmental Protection Agency (EPA), through the OSWER Directive 9200.4-17P (EPA 1999), describes the framework for implementing Monitored Natural Attenuation (MNA) in the section titled "Implementation." While the details of a site-specific approach to implement MNA would be described in a work plan developed subsequently to the remediation study, Table E-1 summarizes how a site-specific approach can meet objectives outlined in the OSWER MNA Directive (EPA 1999) as described in the subsection entitled "Performance Monitoring and Evaluation."

Table E-1. Summary of site-specific approaches available to apply MNA for the Plaquemine Aquifer.

MNA Objective	Site-Specific Approach
<i>"Demonstrate that natural attenuation is occurring according to expectations"</i>	Monitoring locations with observed vinyl chloride concentrations above the drinking water standard can be used to determine the trend in vinyl chloride concentration over time.
<i>"Detect changes in environmental conditions (e.g., hydrogeologic, geochemical, microbiological, or other changes) that may reduce the efficacy of any of the natural attenuation processes"</i>	Monitoring can include assessment of geochemical parameters to augment the existing data and verify that conditions conducive to vinyl chloride degradation processes continue in the aquifer.
<i>"Identify any potentially toxic and/or mobile transformation products"</i>	All transformation products from vinyl chloride are non-toxic; however, reductive dechlorination of DCE can produce vinyl chloride although only in very low concentrations. Monitoring can include all chloroethene compounds and can track the conversion of DCE to vinyl chloride.
<i>"Verify that the plume(s) is not expanding (either down gradient, laterally or vertically)"</i>	Vinyl chloride is sporadically distributed over the remediation study area without a distinct or typical single plume shape. Monitoring locations not currently contaminated by vinyl chloride above the drinking water standard surround the area of contamination within the remediation study area. These wells can continue to be monitored as boundary locations to verify that the vinyl chloride contamination is not expanding. Monitoring locations at multiple depths in the aquifer are also potentially available.

Table E-1. (cont.)

<i>"Verify no unacceptable impact to downgradient receptor"</i>	While the City of Plaquemine water supply wells are not downgradient of the vinyl chloride contamination (see Appendix A), sentry wells to the north and east of the supply wells can be monitored. There are no other receptors identified.
<i>"Detect new releases of contaminants to the environment that could impact the effectiveness of the natural attenuation remedy"</i>	Monitoring can be conducted at numerous locations within the Plaquemine Aquifer for vinyl chloride and other chlorinated ethene compounds to assess any potential indicators of new release(s) or significant continuing source(s), which could impact the effectiveness of the MNA remedy.
<i>"Demonstrate the efficacy of institutional controls that were put in place to protect potential receptors"</i>	Institutional controls such as notification processes can be implemented to protect potential receptors. For example, public notices through mailings, local media, postings, and electronic communications can be used to provide appropriate information.
<i>"Verify attainment of remediation objectives"</i>	Monitoring can continue until concentrations are at or below the drinking water standard. The concentration trends can be reviewed at appropriate time intervals to verify progress toward the remediation objectives with implementation of contingency actions as required for all or part of the aquifer.
<sup>1</sup> Direct quotes from the EPA OSWER Directive 9200.4-17P (EPA 1999), "Performance Monitoring and Evaluation" subsection within the "Implementation" section of the directive. DCE = cis-1,2-dichloroethene	

#### References

EPA. 1999. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*. OSWER Directive 9200.4-17P, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

## Appendix F

### Relative Cost Estimates

This appendix presents relative cost estimates, for the following remediation alternatives.

- Monitored Natural Attenuation
- Pump-and-Treat
- In Situ Aerobic Bioremediation
- In Situ Anaerobic Bioremediation

Cost estimates were assembled based on the approach documented in EPA guidance (EPA 2000a). Costs from RSMeans' Environmental Remediation Cost Data-Unit Price (ECHOS 2005) were used and were adjusted to 2007 costs based on the *Chemical Engineering Plant Cost Index* (CEPCI 2007). Where needed, certain costs were obtained from vendors.

COST ESTIMATE SUMMARY (note 1)	
Monitored Natural Attenuation	
Site: Plaquemine	Overrides: Monitored Natural Attenuation
Location: Louisiana	5 New 4-inch Monitoring Wells, 30 wells sampled
Phase: Screening (-50% to +100%)	Quarterly Monitoring
Base Year: 2007	5-yr review cycle
Date: April 16, 2007	Operating Duration: 20 years (note 1)

CAPITAL COSTS:					
DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Mobilization/Demobilization					
Drill Rig Mob/Demob	1	LS	\$ 2,000	\$ 2,000	
Construction Report	1	LS	\$ 13,000	\$ 13,000	
Site Work					
4-inch monitoring wells to 230 D	5	wells	\$ 23,000	\$ 115,000	
Treatability Test & MNA Evaluation	1	LS	\$ 300,000	\$ 300,000	
Treatment System					
No Treatment					
SUBTOTAL DIRECT CAPITAL COSTS				\$ 432,000	
Contingency	25%			\$ 108,000	
TOTAL DIRECT COSTS (TDC)				\$ 540,000	
Monitoring Pre-Design	10%	TDC		\$ 54,000	
Permitting, Regulatory Compliance	2%	TDC		\$ 10,800	
Construction Quality Assurance, Management	5.0%	TDC		\$ 27,000	
TOTAL INDIRECT COSTS				\$ 91,800	
TOTAL CAPITAL COSTS:				\$ 631,800	

ANNUAL O&M COSTS:					
Well Sampling and Analysis					
Semi-Annual Monitoring 30 locations	60	samples	\$ 1,200	\$ 72,000	
SUBTOTAL				\$ 72,000	
Contingency	20%			\$ 14,400	
TOTAL ANNUAL O&M COSTS				\$ 86,400	

PERIODIC COSTS:					
DESCRIPTION	FREQUENCY (YEARS)	UNIT	UNIT COST	TOTAL	NOTES
5-yr review	5	LS	\$ 100,000	\$ 100,000	
Well Abandonment	20	LS	\$ 3,300	\$ 16,500	Fill 5 wells with bentonite grout

## PRESENT VALUE ANALYSIS:

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (3.6%)	PRESENT VALUE	NOTES
0	Capital Cost	\$ 631,800	\$ 631,800	1.000	\$ 631,800	
1 to 20	Annual O&M Cost	\$ 1,728,000	\$ 86,400	0.907	\$ 1,201,530	
5	Periodic Cost	\$ 100,000	\$ 100,000	0.863	\$ 86,261	5-year report
10	Periodic Cost	\$ 100,000	\$ 100,000	0.744	\$ 74,409	5-year report
15	Periodic Cost	\$ 100,000	\$ 100,000	0.642	\$ 64,186	5-year report
20	Periodic Cost	\$ 116,500	\$ 116,500	0.554	\$ 64,303	Report, well decommission
		\$ 2,776,300			\$ 2,122,690	
TOTAL PRESENT VALUE OF ALTERNATIVE					\$ 2,122,690	
TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST					\$ 2,776,300	

## Footnotes

- 1 Cost estimates are provided for informational purposes only. These cost estimates were conducted for a screening-level evaluation and for assessment of relative cost. Potential costs for right of ways, property acquisition, and the timeframe associated with these actions are not included in these screening-level estimates.
- 2 The time frame for system design and installation is not included in this estimate.

**Background Information for Cost Summary**  
**Plaquemine Remediation Alternative Analysis**

**Alternative: Monitored Natural Attenuation**

DESCRIPTION	BACKGROUND
<b>CAPITAL COSTS:</b>	
<b>Mobilization/Demobilization</b>	
Drill Rig Mob/Demob	Nominal cost for drilling rig mobilization to site.
Construction Report	Report documenting well logs, well locations, and well development.
<b>Site Work</b>	
5 4-inch monitoring wells to 250 ft	Cost to drill and construct 4-inch wells using PVC casing and screens estimated using RSMears' <i>Environmental Remediation Cost Data-Unit Price (ECHOS 2003)</i> .
Treatability Test & MNA Evaluation	Cost to conduct laboratory microcosm treatability tests and conduct an MNA evaluation according to published protocols and produce a monitoring plan.
<b>ANNUAL O&amp;M COSTS:</b>	
Well Sampling and Analysis	\$1,200 per sample cost per well sample with analysis costs, sampling labor, data management, QC, and reporting.
<b>PERIODIC COSTS:</b>	
5-year review	Review groundwater monitoring results to interpret progress of natural attenuation processes with respect to expectations and remediation objectives and report findings.
Well Abandonment	Fill 5 wells with neat cement grout with waste disposal.

COST ESTIMATE SUMMARY (Exhibit 1)	
<b>Pump and Treat</b>	
The Pump-and-Treat alternative was eliminated in the screening evaluation based on effectiveness, implementability, and infeasible alternative criteria of LAC1309 C.2.	
Site: Plaquemine	Description: 10 extraction wells, Discharge to river
Location: Louisiana	12-inch wells 250 ft bgs, 150 ft screen interval.
Phase: Screening (-50% to +100%)	Total pumping rate 20,000 gpm
Base Year: 2001	
Date: April 18, 2007	Operating Duration: 15 years (Exhibit 2)

**CAPITAL COSTS:**

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Mobilization/Demobilization					
Drill Rig Mobil/Demob	1	LS	\$ 2,000	\$ 2,000	
Piping and Treatment Construct	2	LS	\$ 75,000	\$ 150,000	Includes health & safety and permits
Construction Repair	1	LS	\$ 100,000	\$ 100,000	
Site Work					
10 4-inch monitoring wells to 210 ft	10	wells	\$ 23,000	\$ 230,000	
12-inch SS extraction wells to 230 ft	10	wells	\$ 175,300	\$ 1,753,000	Stainless steel screen
10-inch turbine pumps w controls	10	pumps	\$ 70,000	\$ 700,000	Double 13 23 0593, 125 hp
Well Head Protection	10	houses	\$ 6,000	\$ 60,000	Steel pre-engineered building w pad
Electric Power Supply to Equipment	1	LS	\$ 622,000	\$ 622,000	Subject to existing power supplies
Well Head Plumbing, Instrumenty	10	wells	\$ 17,000	\$ 170,000	Includes curves, valves, and equipment in pump house
Piping in Rural Areas	1	LS	\$ 662,000	\$ 662,000	
Piping in Urban Areas	1	LS	\$ 1,010,000	\$ 1,010,000	
Discharge Pumps	1	LS	\$ 162,000	\$ 162,000	
Effluent Discharge Outfalls to River	1	lines	\$ 21,000	\$ 21,000	
Treatment Systems					
Air Stripper, OS 10-20	10	unit	\$ 170,000	\$ 1,700,000	Chris Morgan of Carbonaire
Site Prep, pad, fence	1	LS	\$ 37,000	\$ 37,000	
Arsenic Treatment with Precipitation	1	LS	\$ 3,066,000	\$ 3,066,000	
Arsenic Sludge Handling Equipment	1	LS	\$ 26,500,000	\$ 26,500,000	Centrifuge dewatering
SUBTOTAL DIRECT CAPITAL COSTS				\$ 37,739,000	
Contingency	25%			\$ 9,434,750	
TOTAL DIRECT COSTS (TDC)				\$ 47,173,750	
Engineering Pre-Design	5%	TDC		\$ 2,358,688	
Engineering Design	10%	TDC		\$ 4,717,375	
Permitting, Regulatory Compliance	2%	TDC		\$ 943,475	
Construction Quality Assurance, Management	3.0%	TDC		\$ 2,358,688	
TOTAL INDIRECT COSTS				\$ 10,378,225	
TOTAL CAPITAL COSTS:				\$ 57,551,975	

**ANNUAL O&M COSTS:**

DESCRIPTION	FREQUENCY (YEARS)	UNIT	UNIT COST	TOTAL	NOTES
Extraction, Air Stripper, Pumping to River					
Treatment Equipment Repair	5	episode	\$ 10,000	\$ 50,000	
Treatment for Biofouling	1	year	\$ 81,000	\$ 81,000	
Electric Power	12	months	\$ 240,000	\$ 2,880,000	\$0.12 per KWH, not including A1 and sludge processor
Arsenic Treatment	1	year	\$ 630,000	\$ 630,000	electric power included
Arsenic Sludge Dewatering	1	year	\$ 750,000	\$ 750,000	electric power included
Arsenic Sludge Disposal	1	year	\$ 560,000	\$ 560,000	
Monitoring (30 wells)	30	samples	\$ 1,000	\$ 30,000	
SUBTOTAL				\$ 4,961,000	
Contingency	20%			\$ 996,200	
TOTAL ANNUAL O&M COSTS:				\$ 5,957,200	

**Footnotes**

- Cost estimates are provided for informational purposes only. These cost estimates were conducted for a screening-level evaluation and for assessment of relative cost. Potential costs for rights of ways, property acquisition, and the timeframe associated with these actions are not included in these screening-level estimates.
- The time frame for system design and installation is not included in this estimate.



**COST ESTIMATE SUMMARY (footnote 1)****Pump and Treat**

The Pump-and-Treat alternative was eliminated in the screening evaluation based on effectiveness, implementability, and infeasible alternative criteria of LAC11-509 C.1.

**PERIODIC COSTS:**

DESCRIPTION	FREQUENCY (YEARS)	UNIT	UNIT COST	TOTAL	NOTES
Five Year Review Report	5	EA	\$ 50,000	\$ 50,000	1 report at end of every 5th year
Administrative Management & Oversight	5	10%		\$ 5,000	
<b>SUBTOTAL for Five Year Review</b>				<b>\$ 55,000</b>	
Demobilize Treatment System	15	LS	\$ 500,000	\$ 500,000	Remove equipment and piping
Well Abandonment	15	well	\$ 3,300	\$ 33,000	Fill 10 wells with neat cement grout with waste disposal
Contingency (% of Sum)		25%		\$ 133,250	% of decommissioning activities
Project Management (% of Sum + Cost.)		10%		\$ 76,625	% of decommissioning and contingency, plus permits
<b>SUBTOTAL for closure</b>				<b>\$ 742,875</b>	

**PRESENT VALUE ANALYSIS:**

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (3.0%)	PRESENT VALUE	NOTES
0	Capital Cost	\$ 57,551,975	\$ 57,551,975	1.000	\$ 57,551,975	
1 to 15	Annual O&M Cost	\$ 89,658,000	\$ 5,977,200	10.967	\$ 65,552,119	
5	Periodic Cost	\$ 55,000	\$ 55,000	0.861	\$ 47,643	5-year report
10	Periodic Cost	\$ 55,000	\$ 55,000	0.744	\$ 40,925	5-year report
15	Periodic Cost	\$ 742,875	\$ 742,875	0.642	\$ 476,823	Decommissioning treatment systems
		<b>\$ 148,062,850</b>			<b>\$ 123,669,486</b>	

**TOTAL PRESENT VALUE OF ALTERNATIVE****\$ 123,669,486****TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST****\$ 148,062,850**

### Background Information for Cost Summary Plaquemine Remediation Alternative Analysis

Alternative: Pump and Treat

DESCRIPTION	BACKGROUND
<b>CAPITAL COSTS:</b>	
Mobilization/Demobilization	
Drill Rig Mob/Demob	Nominal cost for drilling rig mobilization to site.
Piping and Treatment Contractor	Procurement of piping and equipment, obtaining access permissions, drilling permits and health and safety plan preparation.
Construction Report	Report documenting well logs, well locations, facility as-built drawings.
Site Work	
10 4-inch monitoring wells to 250 ft	Cost to drill and construct 4-inch wells using PVC casing and screens estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005).
12-inch SS extraction wells to 250 ft	Cost to drill and construct 12-inch wells using Schedule 80 PVC casing and stainless steel screens estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005).
10-inch turbine pumps w controls	Estimate for turbine pump based upon extrapolation of 8" pump cost with 125 horsepower capable of pumping up to 1400 gpm at a head of up to 350 feet water column using <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005).
Well Head Protection	Prefabricated steel buildings placed over well head. Cost estimated from similar construction at other P&T sites.
Electric Power Supply to Equipment	Assumes availability of nearby electric power. Cost estimate based upon power delivered by new pole-mounted conductor with transformer based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices (CEPCI 2007).
Well Head Plumbing, Instruments	Cost estimate based upon valves, level controls, and well-head plumbing costs derived from RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Piping in Rural Areas	High Density Polyethylene Pipe (12" diameter SDR-21) with below ground installation cost based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Piping in Urban Areas	High Density Polyethylene Pipe (12" diameter SDR-21) with below ground installation cost based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices. Urban area installation costs are estimated to be 20 times higher than trenching in rural areas.
Discharge Pumps	Iron/bronze pumps with electric motors estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Effluent Discharge Outfalls to River	Engineering estimate for simple river outfall diffuser.

## Background Information for Cost Summary Plaquemine Remediation Alternative Analysis

### Alternative: Pump and Treat

DESCRIPTION	BACKGROUND
<b>CAPITAL COSTS (could):</b>	
<b>Treatment System</b>	
Air Stripper, OS 10-20	Cost based upon vendor estimate for packed bed fiberglass air stripper package with blower and controls adjusted to 2007 prices.
Site Prep, pad, fence	Site clearing, concrete pad, fencing and gate based upon RSMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Arsenic Treatment with Preoxidation	Arsenic removal by preoxidation with chlorine and enhanced coagulation and filtration of arsenic precipitate. Capital cost estimated using <i>Technologies and Costs for Removal of Arsenic from Drinking Water</i> (EPA 2000b) for As costs adjusted to 2007 costs.
Arsenic Sludge Handling Equipment	Sludge production rates estimated to be 41.5 tons per day water flow. Equipment cost calculated scaling up cost factors in EPA fact sheet on centrifuge thickening and dewatering (EPA 2000c).
Extraction, Air Stripper, Pumping to River Treatment Equipment Repair	Five repair episodes per year assumed at a cost of \$10,000 per year based upon experience with similar systems.
Treatment for Biofouling	Typical annual cost for servicing 10 air strippers for biofouling chemical based upon experience with similar systems.
Electric Power	Power for well pumps, air stripper blowers, transfer pumps at 12 cents per kilowatt-hour.
Arsenic Treatment	Operating & maintenance cost based upon pre-oxidation, coagulation and filtration using <i>Technologies and Costs for Removal of Arsenic from Drinking Water</i> (EPA 2000b) for operating costs adjusted to 2007 costs. Includes electric power costs.
Arsenic Sludge Dewatering	Operating and maintenance cost for dewatering using centrifuge technology based upon an EPA fact sheet (EPA 2000c) adjusted for 2007 prices.
Arsenic Sludge Disposal	Sludge disposal costs based upon a disposal distance of 20 miles using costs provided in <i>Water System Byproducts Treatment and Disposal Cost Document</i> (EPA 1993).
Monitoring (30 wells)	\$1,000 per sample cost per well sample with analysis costs, sampling labor, data management, QC, and reporting.
<b>PERIODIC COSTS:</b>	
Five Year Review Report	\$50,000 per review report based upon nominal reporting costs for similar projects.
Administrative Management & Oversight	Nominal 10% cost of report preparation.
Demobilize Treatment System	Order of magnitude engineering estimate from decommissioning of similar equipment.
Well Abandonment	Fill 10 wells with neat cement grout with waste disposal.

COST ESTIMATE SUMMARY (Footnote 1)	
In Situ Aerobic Bioremediation	
The In Situ Aerobic Bioremediation alternative was eliminated in the screening evaluation based on effectiveness, implementability, and infeasible alternative criteria of LAC31509 C.2.	
Site: Pleasanton	Description: 33 extraction wells, oxygenate, 66 injection wells
Location: Lockdale	12-inch wells 250 ft deep, 150 ft screen interval,
Phase: Screening (-50% to +100%)	Total pumping rate 66,000 gpm
Base Year: 2007	No Arsenic removal
Date: April 16, 2007	Operating Duration: 5 years (Assume 2)

## CAPITAL COSTS:

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Mobilization/Demobilization					
Drill Rig/Mob/De-mob	1	LS	\$ 2,000	\$ 2,000	
Treatment Contractor	2	LS	\$ 75,000	\$ 150,000	Includes health & safety and permits
Construction Report	2	LS	\$ 100,000	\$ 100,000	
Site Work					
10 4-inch monitoring wells to 250 ft	10	well	\$ 23,000	\$ 230,000	
33 12-inch PVC extraction wells to 250 ft	33	well	\$ 153,000	\$ 5,049,000	Includes submersible pump, controls
66 12-inch PVC injection wells to 250 ft	66	well	\$ 82,000	\$ 5,412,000	
Well Head Protection	99	well	\$ 1,000	\$ 99,000	Valve
Electric Power Supply to Equipment	1	LS	\$ 489,000	\$ 489,000	Subject to existing power supplies
Well Head Plumbing, Instruments	99	well	\$ 9,000	\$ 891,000	Includes meter, valves, and controls in valve
Piping in Rural Areas	1	LS	\$ 993,000	\$ 993,000	
Piping in Urban Areas	1	LS	\$ 1,299,000	\$ 1,299,000	
Discharge Pumps	1	LS	\$ 426,000	\$ 426,000	
Treatment System					
Oxygen Injection	33	unit	\$ 37,000	\$ 1,221,000	
Site Prep pad, fence	33	LS	\$ 7,280	\$ 237,600	
Sand Filtration for Iron removal	264	unit	\$ 18,000	\$ 4,752,000	Pressure sand filters
Booster Transfer Pump	33	pumps	\$ 13,000	\$ 429,000	
Transfer Tanks	66	tanks	\$ 11,600	\$ 765,600	
SUBTOTAL DIRECT CAPITAL COSTS				\$ 25,187,200	
Contingency	25%			\$ 6,296,800	
TOTAL DIRECT COSTS (TDC)				\$ 31,484,000	
Engineering Pre-Design	10%	TDC		\$ 3,148,400	
Engineering Design	12%	TDC		\$ 3,778,080	
Permitting, Regulatory Compliance	2%	TDC		\$ 629,680	
Construction Quality Assurance, Management	6.1%	TDC		\$ 1,920,524	
TOTAL INDIRECT COSTS				\$ 9,476,684	
TOTAL CAPITAL COSTS:				\$ 40,960,684	

## ANNUAL O&amp;M COSTS:

Extraction, Oxygenate, Filter Iron, Reinject					
Treatment Equipment Repair	12	episode	\$ 10,000	\$ 120,000	
Treatment for Biofouling	6	months	\$ 44,550	\$ 267,300	
Electric Power	6	months	\$ 639,000	\$ 3,954,000	\$0.12 per KWH
H <sub>2</sub> O <sub>2</sub> (50% solution)	6	months	\$ 17,800	\$ 106,800	
Iron Disposal	6	months	\$ 1,700	\$ 10,200	
Operating Labor	6	months	\$ 36,000	\$ 216,000	4 persons @ 350/hour
Monthly Monitoring (30 wells)	360	samples	\$ 1,000	\$ 360,000	
SUBTOTAL				\$ 5,034,300	
Contingency	20%			\$ 1,006,860	
TOTAL ANNUAL O&M COSTS				\$ 6,041,160	

## Footnote:

- Cost estimates are provided for informational purposes only. These cost estimates were conducted for a screening-level evaluation and for estimation of relative cost. Potential costs for right of ways, property acquisition, and the time/expense associated with these actions are not included in these screening-level estimates.
- The time frame for system design and installation is not included in this estimate.

**COST ESTIMATE SUMMARY (In thousands)****In Situ Aerobic Bioremediation****PERIODIC COSTS:**

DESCRIPTION	FREQUENCY (YEARS)	UNIT	UNIT COST	TOTAL	NOTES
Demobilize Treatment System	once	LS	\$ 500,000	\$ 500,000	Remove equipment and piping
Well Abandonment	once	LS	\$ 3,300	\$ 326,700	Fill 99 wells with neat cement grout
Contingency (4% of Sum)		25%		\$ 207,000	% of decommission activities
Project Management (1% of Sum + Cost.)		10%		\$ 113,000	% of decommission and contingency, plus permits
<b>SUBTOTAL for closure after 6 months of operation</b>				<b>\$ 1,146,700</b>	

**PRESENT VALUE ANALYSIS:**

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (3.0%)	PRESENT VALUE	NOTES
0	Capital Cost	\$ 40,960,684	\$ 40,960,684	1.000	\$ 40,960,684	
1 to 5	Annual O&M Cost	\$ 30,205,800	\$ 6,041,160	2.609	\$ 21,801,340	
5	Periodic Cost	\$ 1,146,700	\$ 1,146,700	0.863	\$ 989,152	Decommission treatment systems
		<b>\$ 72,313,184</b>			<b>\$ 63,751,177</b>	

**TOTAL PRESENT VALUE OF ALTERNATIVE****\$ 63,751,177****TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST****\$ 72,313,184**

### Background Information for Cost Summary Plaquemine Remediation Alternative Analysis

#### Alternative: In Situ Aerobic Bioremediation

DESCRIPTION	BACKGROUND
<b>CAPITAL COSTS:</b>	
Mobilization/Demobilization	
Drill Rig Mob/Demob	Nominal cost for drilling rig mobilization to site.
Treatment Contractor	Procurement of application equipment, obtaining access permissions, drilling permits and health and safety plan preparation.
Construction Report	Report documenting well logs, well locations, treatment system design documents.
<b>Site Work</b>	
10 4-inch monitoring wells to 250 ft	Cost to drill and construct 4-inch wells using PVC casing and screens estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005).
12-inch extraction wells to 250 ft	Cost to drill and construct 12-inch wells using Schedule 80 PVC casing and screens estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005).
12-inch PVC injection wells to 250 ft	Cost to drill and construct 12-inch wells using Schedule 80 PVC casing and screens estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005).
Well Head Protection	Prefabricated concrete vaults placed below grade based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Electric Power Supply to Equipment	Assumes availability of nearby electric power. Cost estimate based upon power delivered by new pole-mounted conductor with transformer based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices (CEPCI 2007).
Well Head Plumbing, Instruments	Cost estimate based upon valves, fittings, and well-head plumbing costs derived from RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Piping in Rural Areas	High Density Polyethylene Pipe (12" diameter SDR-21) with below ground installation cost based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Piping in Urban Areas	High Density Polyethylene Pipe (12" diameter SDR-21) with below ground installation cost based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices. Urban area installation costs are estimated to be 20 times higher than trenching in rural areas.
Discharge Pumps	2000 GPM iron/bronze pumps with electric motors estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Effluent Discharge Outfalls to River	Engineering estimate for simple river outfall diffuser.

### Background Information for Cost Summary Plaquemine Remediation Alternative Analysis

#### Alternative: In Situ Aerobic Bioremediation

DESCRIPTION	BACKGROUND
<b>CAPITAL COSTS (contd):</b>	
Treatment System	
Oxygen Injection System	Hydrogen Peroxide addition system consisting of peroxide storage tank, metering pump, plumbing based upon RSMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Site Prep, pad, fence	Site clearing, concrete pad, fencing and gate based upon RSMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Site Prep, pad, fence	Site clearing, concrete pad, fencing and gate based upon RSMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Transfer Tanks	11,000-gallon steel water tank for equalizing flow of water. Cost based upon RSMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Sand Filtration for iron removal	264 8" Automatic Pressure Filters capable of treating 250 gpm with back wash. Cost based upon RSMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Booster Transfer Pump	2000 gpm transfer pumps with 100 HP electric motors. Cost based upon RSMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Transfer Tanks	Single wall steel tanks with 12,000 gallon capacity. Cost based upon RSMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
<b>ANNUAL O&amp;M COSTS:</b>	
Extraction, Oxygenate, Filter Iron, Reinject	
Treatment Equipment Repair	Twelve repair episodes per year assumed at a cost of \$10,000 per year based upon experience with similar systems.
Treatment for Biofouling	Well and piping clean-out every two months based upon prior experience.
Electric Power	Power for well pumps, oxygenation system, booster pumps for filters, and transfer pumps at 12 cents per kilowatt-hour.
H <sub>2</sub> O <sub>2</sub> (50% solution)	50% solution of hydrogen peroxide at \$0.35 per pound plus delivery from Mobil. Alabama sufficient to provide addition rate of 600 grams per liter of water treated at a pumping rate of 2000 gpm per well.
Iron Disposal	Iron precipitate disposal costs based upon a disposal distance of 20 miles using costs provided in <i>Water System Byproducts Treatment and Disposal Cost Document</i> (EPA 1993).
Operating Labor	4320 person-hours per year at \$50 per hour.
Monthly Monitoring (30 wells)	\$1,000 per sample cost per well sample with analysis costs, sampling labor, data management, QC, and reporting.

**Background Information for Cost Summary  
Plaquemine Remediation Alternative Analysis**

**Alternative: In Situ Aerobic Bioremediation**

DESCRIPTION	BACKGROUND
<b>PERIODIC COSTS:</b>	
Demobilize Treatment System	Order of magnitude engineering estimate from decommissioning of similar equipment.
Well Abandonment	Fill 99 wells with neat cement grout with waste disposal.



COST ESTIMATE SUMMARY (footnote 1)	
<b>In Situ Anaerobic Bioremediation</b>	
The In Situ Anaerobic Bioremediation alternative was characterized in the screening evaluation based on effectiveness, implementability, and infeasible alternative criteria of LAC31309 C.2.	
Site: Hagerman	Description: 33 extraction wells, molasses, 66 injection wells
Location: Location	12-inch wells 250 ft bgs, 150 ft screen interval.
Phase: Screening (-50% to +100%)	Total pumping rate 66,000 gpm
Base Year: 2007	No Arsenic removal
Date: April 14, 2007	Operating Duration: 5 years (footnote 2)

**CAPITAL COSTS:**

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Mobilization/Demobilization					
Drill Rig Mob/Demob	1	LS	\$ 2,000	\$ 2,000	
Treatment Contractor	2	LS	\$ 75,000	\$ 150,000	Includes health & safety and permits
Construction Report	1	LS	\$ 100,000	\$ 100,000	
Site Work					
10 4-inch monitoring wells to 250 ft	10	wells	\$ 23,000	\$ 230,000	
12-inch PVC extraction wells to 250 ft	33	wells	\$ 133,000	\$ 5,049,000	
12-inch PVC injection wells to 250 ft	66	wells	\$ 82,000	\$ 5,412,000	
Well Head Protection	99	vents	\$ 1,000	\$ 99,000	Vents
Electric Power Supply to Equipment	1	LS	\$ 470,000	\$ 470,000	Subject to existing power supplies
Well Head Plumbing, Instruments	99	wells	\$ 9,000	\$ 891,000	Includes cures, valves, and controls in vents
Piping in Rural Areas	1	LS	\$ 995,000	\$ 995,000	
Piping in Urban Areas	1	LS	\$ 1,299,000	\$ 1,299,000	
Discharge Pumps	33	pumps	\$ 12,900	\$ 425,700	
Treatment Systems					
Molasses Addition System	33	unit	\$ 45,300	\$ 1,494,900	
Site Prep, pad, fence	33	LS	\$ 7,200	\$ 237,600	
Transfer Tanks	33	tanks	\$ 11,600	\$ 382,800	
<b>SUBTOTAL DIRECT CAPITAL COSTS</b>				<b>\$ 17,234,000</b>	
Contingency	25%			\$ 4,309,500	
<b>TOTAL DIRECT COSTS (TDC)</b>				<b>\$ 21,543,500</b>	
Engineering Pre-Design	10%	TDC		\$ 2,154,350	
Engineering Design	12%	TDC		\$ 2,585,200	
Permitting, Regulatory Compliance	2%	TDC		\$ 430,930	
Construction Quality Assurance Management	6.1%	TDC		\$ 1,314,318	
<b>TOTAL INDIRECT COSTS</b>				<b>\$ 6,485,798</b>	
<b>TOTAL CAPITAL COSTS:</b>				<b>\$ 28,029,298</b>	

**ANNUAL O&M COSTS:**

DESCRIPTION	FREQUENCY (YEARS)	UNIT	UNIT COST	TOTAL	NOTES
Extraction, Substrate Addition, Reinject					
Treatment Equipment Repair	12	episode	\$ 10,000	\$ 120,000	
Treatment for Biofouling	6	months	\$ 44,350	\$ 267,300	
Electric Power	6	months	\$ 496,915	\$ 2,981,488	\$0.12 per KWH
Molasses	6	months	\$ 413,093	\$ 2,478,560	
Operating Labor	6	months	\$ 27,000	\$ 162,000	3 persons @ \$50/hr
Monthly Monitoring (30 wells)	360	samples	\$ 1,000	\$ 360,000	
<b>SUBTOTAL</b>				<b>\$ 6,369,348</b>	
Contingency	20%			\$ 1,273,870	
<b>TOTAL ANNUAL O&amp;M COSTS</b>				<b>\$ 7,643,218</b>	

**Footnotes:**

1 Cost estimates are provided for informational purposes only. These cost estimates were conducted for a screening-level evaluation and for assessment of relative cost. Potential costs for right of ways, property acquisition, and the timeframe associated with these actions are not included in these screening-level estimates.

2 The time frame for system design and installation is not included in this estimate.

COST ESTIMATE SUMMARY (Footnote 1)	
In Situ Anaerobic Bioremediation	
The In Situ Anaerobic Bioremediation alternative was eliminated in the screening evaluation based on effectiveness, implementability, and infeasible alternative criteria of LACU 309 C.1.	

## PERIODIC COSTS:

DESCRIPTION	FREQUENCY (YEARS)	UNIT	UNIT COST	TOTAL	NOTES
Demobilize Treatment System	once	LS	\$ 500,000	\$ 500,000	Remove equipment and piping
Well Abandonment	once	LS	\$ 3,300	\$ 326,700	Fill 99 wells with seal cement grout with waste disposal
Contingency (% of Sum)		25%		\$ 206,675	% of decommissioning activities
Project Management (% of Sum + Cost.)		10%		\$ 113,338	% of decommissioning and contingency, plus permits
SUBTOTAL for closure after 6 months of operation				\$ 1,146,713	

## PRESENT VALUE ANALYSIS:

YEAR	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (1.0%)	PRESENT VALUE	NOTES
0	Capital Cost	\$ 28,033,298	\$ 28,033,298	1.000	\$ 28,033,298	
1 to 5	Annual O&M Cost	\$ 38,216,091	\$ 7,643,218	3.609	\$ 27,583,101	
5	Periodic Cost	\$ 1,146,713	\$ 1,146,713	0.863	\$ 989,164	Decommission treatment systems
		\$ 67,396,101			\$ 56,605,563	

## TOTAL PRESENT VALUE OF ALTERNATIVE

**\$ 56,605,563**

## TOTAL NON-DISCOUNTED CONSTANT DOLLAR COST

\$ 67,396,101

## Background Information for Cost Summary Plaquemine Remediation Alternative Analysis

### Alternative: In Situ Anaerobic Bioremediation

DESCRIPTION	BACKGROUND
<b>CAPITAL COSTS:</b>	
Mobilization/Demobilization	
Drill Rig Mob/Demob	Nominal cost for drilling rig mobilization to site.
Treatment Contractor	Procurement of application equipment, obtaining access permissions, drilling permits and health and safety plan preparation.
Construction Report	Report documenting well logs, well locations, treatment system design documentation.
Site Work	
10 4-inch monitoring wells to 250 ft	Cost to drill and construct 4-inch wells using PVC casing and screens estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005).
12-inch extraction wells to 250 ft	Cost to drill and construct 12-inch wells using Schedule 80 PVC casing and screens estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005).
12-inch PVC injection wells to 250 ft	Cost to drill and construct 12-inch wells using Schedule 80 PVC casing and screens estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005).
Well Head Protection	Prefabricated concrete vaults placed below grade based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Electric Power Supply to Equipment	Assumes availability of near-by electric power. Cost estimate based upon power delivered by new pole-mounted conductor with transformer based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices (CEPCI 2007).
Well Head Plumbing, Instruments	Cost estimate based upon valves, fittings, and well-head plumbing costs derived from RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Piping in Rural Areas	High Density Polyethylene Pipe (12" diameter SDR-21) with below ground installation cost based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Piping in Urban Areas	High Density Polyethylene Pipe (12" diameter SDR-21) with below ground installation cost based upon RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices. Urban area installation costs are estimated to be 20 times higher than trenching in rural areas.
Discharge Pumps	2000 GPM iron/bronze pumps with electric motors estimated using RSMMeans' <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Effluent Discharge Outfalls to River	Engineering estimate for simple river outfall diffuser.

### Background Information for Cost Summary Plaquemine Remediation Alternative Analysis

#### Alternative: In Situ Anaerobic Bioremediation

DESCRIPTION	BACKGROUND
<b>CAPITAL COSTS (cont'd):</b>	
Treatment System	
Molasses Addition System	Cost based upon 8000 gallon molasses storage tank, piping, feed pump and controls based upon RSMean's <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted to 2007 prices.
Site Prep, pad, fence	Site clearing, concrete pad, fencing and gate based upon RSMean's <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
Transfer Tanks	11,000-gallon steel water tank for equalizing flow of water. Cost based upon RSMean's <i>Environmental Remediation Cost Data-Unit Price</i> (ECHOS 2005) adjusted using preliminary cost factors to 2007 prices.
<b>ANNUAL O&amp;M COSTS:</b>	
Extraction, Substrate Addition, Reinject Treatment Equipment Repair	Twelve repair episodes per year assumed at a cost of \$10,000 per year based upon experience with similar systems.
Treatment for Biofouling	Well and piping clean-out every two months based upon prior experience.
Electric Power	Power for well pumps, molasses feed pumps, transfer pumps at 12 cents per kilowatt-hour.
Molasses	Molasses at \$137 per ton delivered sufficient to provide addition rate of 250 mg per liter of water treated at a pumping rate of 2000 gpm per well.
Operating Labor	3240 person-hours per year at \$50 per hour.
Monthly Monitoring (30 wells)	\$1,000 per sample cost per well sample with analysis costs, sampling labor, data management, QC, and reporting.
<b>PERIODIC COSTS:</b>	
Demobilize Treatment System	Order of magnitude engineering estimate from decommissioning of similar equipment.
Well Abandonment	Fill 99 wells with neat cement grout with waste disposal.

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## Appendix G

### Scoping Calculations for Technologies

This appendix presents details of scoping calculations used for the pump-and-treat (P&T), chemical oxidation, in situ aerobic bioremediation, and in situ anaerobic bioremediation technologies.

#### G.1 Pump-and-Treat

Pump-and Treat (P&T) systems physically extract or remove groundwater from the aquifer. The extracted groundwater is then treated as needed to remove contaminants and other constituents in the water that are not suited for re-injection into the aquifer or to be discharged to surface water. The well network design for a P&T system must consider capture of the groundwater in the presence of the regional gradient, effects of water recharge boundaries such as the Mississippi River, appropriate re-injection or discharge of treated water, and logistical constraints for well and treatment system location (e.g., city infrastructure, private property). For scoping calculations, a P&T system using groundwater extraction followed by surface water discharge was assessed. However, the scoping calculations for capture with a recirculation (extraction and re-injection) system were also conducted because this type of system is relevant not only to a P&T system but also to the alternatives that require distribution of additives within the aquifer. The calculation for the effectiveness of capture of contaminated groundwater is important for the spacing distance of extraction wells in the system design. Calculations based on mathematical relationships between pumping rates in wells and the resulting influence on the aquifer were performed to assess possible extraction well spacings for the design of the system (Cohen et al., 1997). The results of these calculations are described in the following paragraphs.

An extraction rate of 2,000 gpm per well was used for P&T system calculations. Whiteman (1972) provides a list of pumping wells and their extraction rates within the Plaquemine Aquifer. These data indicate that a 2,000 gpm extraction rate from a 150-ft well screen interval is within the midrange of extraction well performance for the aquifer. The relatively high extraction rate for the P&T system was selected based on the premise that the P&T system would be designed to remediate the aquifer in a short period of time compared to the timeframe for natural attenuation. That is, if the P&T system remediation timeframe is not better than the natural attenuation remediation timeframe, then the additional effort associated with implementing the P&T system would not provide added value.

Using an extraction rate of 2,000 gpm per well, the well spacing between extraction wells was estimated for a confined aquifer at two regional gradients of 0.00042 ft/ft and 0.004 ft/ft using the aquifer properties listed in Table A-1 (Appendix A). The lower gradient assumes that water will be extracted and disposed at the surface (e.g., in the river). The higher gradient was

estimated based on assuming the paired injection/extraction well lines configuration are at a distance of 2,000 ft between lines with approximately 8 ft of head difference between the injection and extraction locations (i.e., a groundwater recirculation system). For a recirculation system, injection wells would re-inject water at a rate of 1,000 gpm per well (well capacity for injection of about one half of extraction rate per Driscoll [1986]). Capture analysis for a line of wells perpendicular to the regional gradient was conducted for the two scenarios described above. For the average regional gradient of 0.00042 ft/ft (extraction and surface disposal), an extraction well spacing of 2,000 ft between wells provides capture if the well line contains at least four wells. For a gradient of 0.004 ft/ft (recirculation system conditions) an extraction well spacing of 600 ft between wells provides capture if the well line contains at least four wells.

A P&T system based on extraction of groundwater, treatment, and then discharge to the Mississippi River was used as the conceptual design for evaluation of the P&T alternative. If treatment is necessary to meet discharge requirements, treatment of water at the surface would consist of an oxidation pre-treatment, pH adjustment and reagent addition followed by flocculation and clarification systems to remove arsenic precipitate and other suspended solids; and air stripping to remove vinyl chloride. The arsenic treatment system would be based on a recent EPA document describing arsenic treatment technologies (EPA 2002). Use of air stripping would be a presumptive remedy to remove vinyl chloride from the water. The purpose of this treatment would be to clean the water sufficiently so that it could be discharged to surface water. Potentially, a P&T remedy could be implemented without treatment of the water prior to discharge into the Mississippi River. A permit for discharge of water contaminated with vinyl chloride and arsenic would need to be obtained. Eliminating the aboveground treatment equipment would decrease the overall cost of the P&T alternative. However, the well and transfer piping infrastructure would remain essentially the same. Thus, the evaluation with respect to effectiveness and implementability would not change significantly.

## G.2 Chemical Oxidation

For many aquifers, the organic carbon content of the aquifer sediments is an important source of oxidizable material. The average organic carbon content within the Plaquemine Aquifer based on 32 measurements equates to a fraction of organic carbon value of 0.0019 g-organic carbon/g-soil (PTS 2006).

Table D-3 (Appendix D) shows the estimated moles of oxidant demand (based on molecular oxygen oxidation of all of the organic carbon) for the entire remediation study area and for selected radial distances from an injection point. These estimates equate to a unit oxidant demand of 0.089 mol-O<sub>2</sub>/kg-soil for an  $f_{oc}$  of 0.0019. For comparison, Schnarr et al. (1998) measured an oxidant demand of 0.025 mol-KMnO<sub>4</sub>/kg-soil for an  $f_{oc}$  of 0.00027 in oxidation tests at a field test site in a sandy aquifer. Converting the oxidant demand from Schnarr et al. (1998) into moles of molecular oxygen and assuming a proportional relationship to the  $f_{oc}$ , the measured oxidant demand by Schnarr et al. (1998) is equivalent to 0.131 mol-O<sub>2</sub>/kg-soil for an  $f_{oc}$  of 0.0019. The unit oxidant demand in Schnarr et al. (1998) may be higher than estimated in

Table D-3 due to the inclusion of mineral oxidant demand by Schnarr et al. (1998). Using the oxidant demand estimates from Table D-3, the mass of a strong oxidant such as  $\text{KMnO}_4$  required to overcome this demand and oxidize the vinyl chloride contamination can be estimated. For the total treatment volume, an oxygen demands (as  $\text{O}_2$ ) of 31.7 billion mol (foc = 0.0019) and 8.8 billion mol (foc = 0.00027 from Schnarr et al. 1998) equate to approximately 5.7 billion kg and 1.8 billion kg of  $\text{KMnO}_4$ , respectively, required to overcome the oxidant demand.

### G.3 In Situ Aerobic Bioremediation

Vinyl chloride can be directly oxidized by certain bacteria in the presence of molecular oxygen (e.g., Hartmans and de Bont 1992) or can be co-metabolically oxidized by other bacteria in the presence of molecular oxygen and substrates such as methane, toluene, and phenol (e.g., Chang and Alvarez-Cohen 1996). For either type of metabolism, a key factor in stimulating microbial activity in situ is to supply sufficient oxygen to support the microbial reactions and to overcome the oxygen demand of the aquifer. Because weak oxidants, such as molecular oxygen, are typically used to support biological activity, the organic carbon content of the aquifer solids imposes a lower oxygen demand than for strong oxidants such as permanganate used in chemical oxidation. However, the oxidation demand of dissolved iron(II), methane, and organic carbon must be overcome. The solubility of oxygen (in equilibrium with air) is only on the order of 10 mg/L or about 0.31 mmol/L. The average dissolved-phase concentrations of iron(II) (2.4 mg/L), methane (2.7 mg/L), and total organic carbon (TOC) (3.2 mg/L) in the remediation study area collectively exert a soluble oxygen demand of 0.53 mmol/L. Depending on the microbial ecology of the aquifer, methane may not rapidly oxidize, and the soluble oxygen demand would be about 0.19 mmol/L.

A groundwater recirculation system could be used to distribute oxygen in a treatment volume within the aquifer. However, as discussed in the preceding paragraphs, the groundwater may contain more oxygen demand than can be overcome by oxygen at the ambient-air solubility limit. Potentially, hydrogen peroxide or pure oxygen could be injected to overcome this oxygen demand and leave a residual oxygen concentration of near 10 mg/L in the injected groundwater. Issues such as fouling from iron would need to be resolved through removal of the iron prior to re-injection. Additionally, a permit for re-injection of groundwater would be required. Essentially, similar infrastructure to a P&T system for water handling (extraction and re-injection) would be needed.

Push-pull or direct injection of oxygen releasing agents would have only a very small radius of influence based on the thickness of the aquifer and the large volume to radial distance ratio. To distribute an agent to a radius of 20 ft from the well, assuming that the agent fills 10% of the pore volume, 40,000 L of agent would be required. Potentially, the movement of groundwater during seasonal variation in the hydraulic gradient may distribute dissolved oxygen from an oxygen-releasing agent over a larger volume. The total mass of agent needed to oxidize the soluble oxygen demand and leave a residual oxygen concentration of 10 mg/L can be calculated based on the information in Appendix D. With about 0.5 mmol/L oxygen demand plus an



additional 0.31 mmol/L to provide 10 mg/L of residual dissolved oxygen, about 1.5 million kg of molecular oxygen additive would be required. If it is assumed that the methane does not create an oxygen demand, about 960,000 kg of molecular oxygen additive would be required. Oxygen release agents have not been applied at this scale. Based on this analysis, use of oxygen release agents is considered to be ineffective for volumetric treatment at the scale of the remediation study. Because there are no smaller, distinct, high-concentration areas within the remediation study area that are more typical of the type of conditions for which oxygen release agents are applied, targeted applications will also not be considered as part of the remediation study. Therefore, oxygen release agents are eliminated as a remedial alternative.

If methanotrophic bacteria (bacteria that use methane as a substrate) are present in the aquifer, co-metabolic vinyl chloride degradation may occur. The methane already dissolved in the groundwater may be sufficient to catalyze this degradation after addition of sufficient oxygen. There are insufficient data to establish whether more methane would need to be added. For the purpose of the remediation study, co-metabolic degradation of vinyl chloride under aerobic conditions was not considered as a separate remediation technology. Instead, the study evaluated biostimulation through addition of only oxygen to the aquifer. The oxygen-only alternative is expected to perform similarly to aerobic co-metabolic degradation but at a similar and likely lower cost due to the need to add only oxygen and not a co-substrate.

#### **G.4 In Situ Anaerobic Bioremediation**

Vinyl chloride can be directly reduced to ethene by some bacteria as part of anaerobic reductive dechlorination reactions (e.g., DeBruin et al. 1992; Freedman and Gossett 1989). This dechlorination reaction is mediated by fewer bacterial species than the number of bacterial species that can reduce more highly chlorinated ethenes such as trichloroethene. The dechlorination reaction also requires that an appropriate substrate is present and that the vinyl chloride-dechlorinating bacteria can effectively compete for the substrate against other microorganisms that use the same substrate with other electron acceptors. Alternatively, vinyl chloride can be degraded as a substrate by bacteria that couple oxidation of vinyl chloride to reduction of another anaerobic electron acceptor such as iron(III) (e.g., Bradley and Chapelle 1997). This type of vinyl chloride oxidation can occur under anaerobic conditions under natural conditions, and is not necessarily stimulated by addition of any additive.

A groundwater recirculation system could be used to distribute a substrate within the aquifer to attempt enhancing reductive dechlorination of vinyl chloride. However, the success in stimulating vinyl chloride dechlorination versus other types of anaerobic activity that do not destroy vinyl chloride is dependent on the microbial ecology and groundwater geochemistry (e.g., presence of other electron acceptors). For the groundwater recirculation, a permit for re-injection of groundwater would be required. Essentially, similar infrastructure to a P&T system for water handling (extraction and re-injection) would be needed.

Push-pull or direct injection of long-duration substrates would have only a very small radius of influence based on the thickness of the aquifer and the large volume to radial distance ratio. To distribute an agent to a radius of 20 ft from the well, assuming that the agent fills 10% of the pore volume, 40,000 L of agent would be required. Potentially, the movement of groundwater during seasonal variation in the hydraulic gradient may distribute substrate over a larger volume. However, the populations of bacteria that can use the substrate will increase over time near the injection site for the substrate and consume it rapidly before it can distribute beyond the initial injection zone. Long-term substrates have not been applied at this scale. Based on this analysis, use of long-duration substrates is considered to be ineffective for volumetric treatment at the scale of the remediation study. Because there are no smaller, distinct, high-concentration areas within the remediation study area that are more typical of the type of conditions for which long-duration substrates are applied, targeted applications will also not be considered as part of the remediation study. Therefore, long-duration substrates are eliminated as a remedial alternative.

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## **Appendix H**

### **Data for Arsenic Valence States**

## **Appendix H**

### **Data for Arsenic Valence State**

This appendix lists the available data for arsenic ion in the +3 and +5 valence states. This information provides insight into the oxidation/reduction conditions in the aquifer. Reduced conditions are indicated when arsenic is primarily in the +3 valence state. Predominance of arsenic in the +5 valence state would indicate more oxidizing conditions. Data presented below indicate generally more reduced conditions.

Table H-1. Arsenic ion (+3 and +5 valences) data.

Lab	Sample Date	Sample Point	Sample Type	Analyte	PQLMDL	Result	Qualifier	Units
WCAS	7/12/2004	DEQ A	TRG	Arsenic (+3), Dissolved	0.2	12.1		ppb
WCAS	7/12/2004	DEQ A	TRG	Arsenic (+3), Total	0.2	13.8		ppb
WCAS	7/12/2004	DEQ A	TRG	Arsenic (+5), Dissolved	0.5	0.8		ppb
WCAS	7/12/2004	DEQ A	TRG	Arsenic (+5), Total	0.5	3.1		ppb
WCAS	7/12/2004	DEQ EE	TRG	Arsenic (+3), Dissolved	0.2	8.83		ppb
WCAS	7/12/2004	DEQ EE	TRG	Arsenic (+3), Dissolved	0.2	8.71		ppb
WCAS	7/12/2004	DEQ EE	TRG	Arsenic (+3), Total	0.2	7.68		ppb
WCAS	7/12/2004	DEQ EE	TRG	Arsenic (+3), Total	0.2	7.63		ppb
WCAS	7/12/2004	DEQ EE	TRG	Arsenic (+5), Dissolved	0.5	1		ppb
WCAS	7/12/2004	DEQ EE	TRG	Arsenic (+5), Dissolved	0.5	ND		ppb
WCAS	7/12/2004	DEQ EE	TRG	Arsenic (+5), Total	0.5	5.1		ppb
WCAS	7/12/2004	DEQ EE	TRG	Arsenic (+5), Total	0.5	5.7		ppb
WCAS	7/12/2004	DEQ P	TRG	Arsenic (+3), Dissolved	0.2	11.6		ppb
WCAS	7/12/2004	DEQ P	TRG	Arsenic (+3), Total	0.2	14		ppb
WCAS	7/12/2004	DEQ P	TRG	Arsenic (+5), Dissolved	0.5	ND		ppb
WCAS	7/12/2004	DEQ P	TRG	Arsenic (+5), Total	0.5	2.4		ppb
WCAS	7/12/2004	DEQ V	TRG	Arsenic (+3), Dissolved	0.2	21.4		ppb
WCAS	7/12/2004	DEQ V	TRG	Arsenic (+3), Total	0.2	22.9		ppb
WCAS	7/12/2004	DEQ V	TRG	Arsenic (+5), Dissolved	0.5	1.5		ppb
WCAS	7/12/2004	DEQ V	TRG	Arsenic (+5), Total	0.5	1.3		ppb
WCAS	7/7/2004	EPA-1	TRG	Arsenic (+3), Dissolved	0.2	10.1		ppb
WCAS	7/7/2004	EPA-1	TRG	Arsenic (+3), Total	0.2	10.6		ppb
WCAS	7/7/2004	EPA-1	TRG	Arsenic (+5), Dissolved	0.5	2.1		ppb
WCAS	7/7/2004	EPA-1	TRG	Arsenic (+5), Total	0.5	2.3		ppb
WCAS	7/7/2004	EPA-2	TRG	Arsenic (+3), Dissolved	0.2	8.26		ppb
WCAS	7/7/2004	EPA-2	TRG	Arsenic (+3), Total	0.2	3.83		ppb
WCAS	7/7/2004	EPA-2	TRG	Arsenic (+5), Dissolved	0.5	1.5		ppb
WCAS	7/7/2004	EPA-2	TRG	Arsenic (+5), Total	0.5	6.3		ppb
WCAS	7/7/2004	EPA-4	TRG	Arsenic (+3), Dissolved	0.2	38.8		ppb
WCAS	7/7/2004	EPA-4	TRG	Arsenic (+3), Total	0.2	39		ppb
WCAS	7/7/2004	EPA-4	TRG	Arsenic (+5), Dissolved	0.5	3.3		ppb
WCAS	7/7/2004	EPA-4	TRG	Arsenic (+5), Total	0.5	2.8		ppb
WCAS	7/7/2004	EPA-5	TRG	Arsenic (+3), Dissolved	0.2	40.8		ppb
WCAS	7/7/2004	EPA-5	FD	Arsenic (+3), Dissolved	0.2	40.7		ppb
WCAS	7/7/2004	EPA-5	TRG	Arsenic (+3), Total	0.2	38.1		ppb
WCAS	7/7/2004	EPA-5	FD	Arsenic (+3), Total	0.2	38.6		ppb
WCAS	7/7/2004	EPA-5	TRG	Arsenic (+5), Dissolved	0.5	2.4		ppb
WCAS	7/7/2004	EPA-5	FD	Arsenic (+5), Dissolved	0.5	1.7		ppb
WCAS	7/7/2004	EPA-5	TRG	Arsenic (+5), Total	0.5	5.1		ppb
WCAS	7/7/2004	EPA-5	FD	Arsenic (+5), Total	0.5	5		ppb
WCAS	8/10/2004	PZ-34	TRG	Arsenic (+3), Dissolved	0.1	5.7		ppb
WCAS	8/10/2004	PZ-34	TRG	Arsenic (+3), Total	0.1	7.6		ppb
WCAS	8/10/2004	PZ-34	TRG	Arsenic (+5), Dissolved	0.1	0.1		ppb
WCAS	8/10/2004	PZ-34	TRG	Arsenic (+5), Total	0.1	0.2		ppb
WCAS	7/8/2004	PZ-39	TRG	Arsenic (+3), Dissolved	0.2	5.3		ppb
WCAS	7/8/2004	PZ-39	TRG	Arsenic (+3), Total	0.2	5.3		ppb
WCAS	7/8/2004	PZ-39	TRG	Arsenic (+5), Dissolved	0.5	ND		ppb
WCAS	7/8/2004	PZ-39	TRG	Arsenic (+5), Total	0.5	ND		ppb
WCAS	7/8/2004	PZ-40	TRG	Arsenic (+3), Dissolved	0.2	ND		ppb
WCAS	7/8/2004	PZ-40	TRG	Arsenic (+3), Total	0.2	ND		ppb
WCAS	7/8/2004	PZ-40	TRG	Arsenic (+5), Dissolved	0.5	16.3		ppb
WCAS	7/8/2004	PZ-40	TRG	Arsenic (+5), Total	0.5	16.6		ppb

Table H-1. contd.

Lab	Sample Date	Sample Point	Sample Type	Analyte	EQUMDL	Result	Qualifier	Units
WCAS	7/8/2004	PZ-42	TRG	Arsenic (+3), Total	0.2	ND		ppb
WCAS	7/8/2004	PZ-42	TRG	Arsenic (+3), Total	0.2	ND		ppb
WCAS	7/8/2004	PZ-42	TRG	Arsenic (+5), Total	0.5	ND		ppb
WCAS	7/8/2004	PZ-42	TRG	Arsenic (+5), Total	0.5	ND		ppb
WCAS	7/8/2004	PZ-43	TRG	Arsenic (+3), Dissolved	0.2	35.1		ppb
WCAS	7/8/2004	PZ-43	TRG	Arsenic (+3), Total	0.2	35		ppb
WCAS	7/8/2004	PZ-43	TRG	Arsenic (+5), Dissolved	0.5	2.3		ppb
WCAS	7/8/2004	PZ-43	TRG	Arsenic (+5), Total	0.5	2.9		ppb
WCAS	7/6/2004	Sentinel 1	TRG	Arsenic (+3), Dissolved	0.2	4.34		ppb
WCAS	7/6/2004	Sentinel 1	TRG	Arsenic (+3), Total	0.2	4.27		ppb
WCAS	7/6/2004	Sentinel 1	TRG	Arsenic (+5), Dissolved	0.5	1.1		ppb
WCAS	7/6/2004	Sentinel 1	TRG	Arsenic (+5), Total	0.5	0.8		ppb
WCAS	7/6/2004	Sentinel 2	TRG	Arsenic (+3), Dissolved	0.2	13.4		ppb
WCAS	7/6/2004	Sentinel 2	TRG	Arsenic (+3), Total	0.2	13.7		ppb
WCAS	7/6/2004	Sentinel 2	TRG	Arsenic (+5), Dissolved	0.5	1.4		ppb
WCAS	7/6/2004	Sentinel 2	TRG	Arsenic (+5), Total	0.5	1.2		ppb
WCAS	7/6/2004	Sentinel 3	TRG	Arsenic (+3), Dissolved	0.2	2.9		ppb
WCAS	7/6/2004	Sentinel 3	TRG	Arsenic (+3), Total	0.2	2.84		ppb
WCAS	7/6/2004	Sentinel 3	TRG	Arsenic (+5), Dissolved	0.5	ND		ppb
WCAS	7/6/2004	Sentinel 3	TRG	Arsenic (+5), Total	0.5	ND		ppb
WCAS	7/6/2004	Sentinel 4	TRG	Arsenic (+3), Dissolved	0.2	1.93		ppb
WCAS	7/6/2004	Sentinel 4	TRG	Arsenic (+3), Total	0.2	2.4		ppb
WCAS	7/6/2004	Sentinel 4	TRG	Arsenic (+5), Dissolved	0.5	0.6		ppb
WCAS	7/6/2004	Sentinel 4	TRG	Arsenic (+5), Total	0.5	0.6		ppb